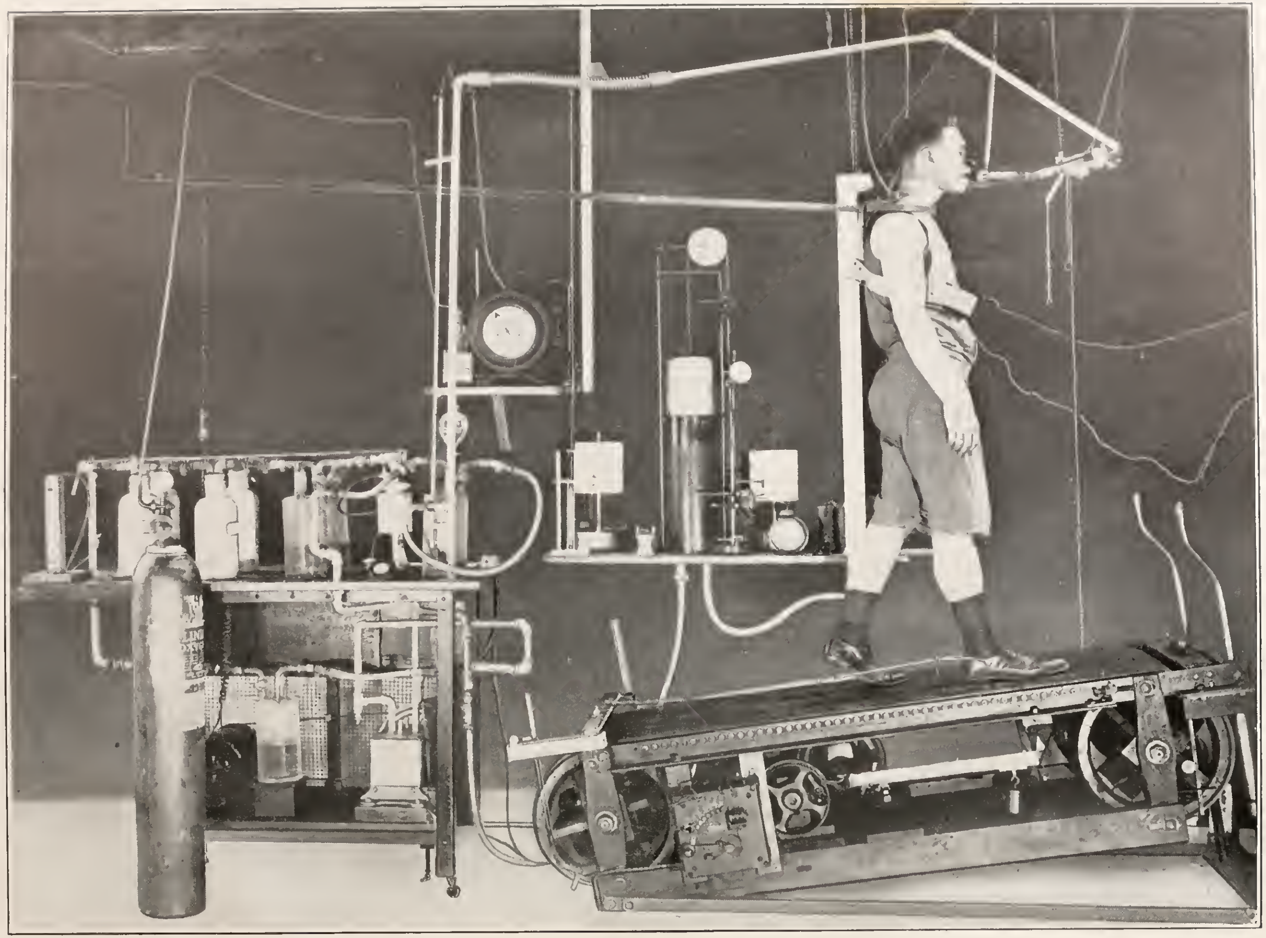

Subject and apparatus in readiness for experiment.

GASEOUS EXCHANGE AND PHYSIOLOGICAL REQUIREMENTS FOR LEVEL AND GRADE WALKING

By Henry Monmouth Smith

Published by the Carnegie Institution of Washington
Washington, April, 1922

CARNEGIE INSTITUTION OF WASHINGTON
Publication No. 309

PRESS OF GIBSON BROTHERS
WASHINGTON

MARINE BIOLOGICAL

PREFACE.

The following report presents the results of a series of experiments carried out in continuation of a plan of study at the Nutrition Laboratory on the energy expenditure during muscular work, and supplements the report of Benedict and Murschhauser: Energy Transformations during Horizontal Walking.

The author is indebted to the Director, Dr. Francis G. Benedict, for his constant interest and criticism as the work progressed, and to Miss A. N. Darling for her painstaking supervision of the editorial work in preparing the material for publication. He is also indebted to Mr. Karl H. Brown for his interest and fidelity in the difficult task of recording the pulse-rates and to Mr. William H. Leslie for much of the labor involved in the calculations, and preparation of the tables.

Nutrition Laboratory of the
Carnegie Institution of Washington,
Boston, Massachusetts, April 23, 1921.

CONTENTS.

PAGE.
Introduction 1
Researches by other investigators on energy requirements for walking 3
  Horizontal walking 3
    General considerations with regard to previous researches on horizontal walking 7
  Grade walking 8
    General considerations with regard to previous work on grade walking 15
Plan of study 16
Methods of measurement 18
  Universal respiration apparatus 20
    Tests of the universal respiration apparatus 25
  Treadmill 27
  Measurement of the step-lift 30
  Method of step-counting 33
  Apparatus for determining the pulse-rate 33
    Oscillograph 34
    Cambridge string galvanometer 34
    Electrodes 35
    Technique for securing records of the pulse-rate 36
  Determination of the body-temperature 36
  Determination of the blood-pressure 37
  Routine of experiments 38
Subjects 41
Statistics of experiments 42
Discussion of results 90
  Basal metabolism 90
  Experiments with subject standing 94
    Metabolism during standing 94
      Carbon-dioxide elimination 94
      Oxygen consumption 95
      Respiratory quotient 95
      Heat-output 96
      General summary of measurements of metabolism during standing . . . 97
      Comparison of metabolism for lying and standing positions 100
    Physiological effects of standing 101
      Respiration-rate with subject standing 101
      Pulmonary ventilation with subject standing 103
      Pulse-rate with subject standing 106
      Rectal body-temperature with subject standing 113
      Blood-pressure with subject standing 115
  Experiments with horizontal walking 116
    Metabolism of subjects while walking on a level 116
      Total metabolism during horizontal walking 116
      Increment in metabolism due to horizontal walking 120
        Total increment in heat-production 139
        Increment in heat per horizontal kilogrammeter 139
    Effect of speed upon metabolism in horizontal walking 143
      Effect of speed upon total heat-output 145
      Effect of speed upon total increase in heat-output 146
      Effect of speed upon increase in heat per horizontal kilogrammeter . . . 147
    Experiments with subject "marking time" 150
    Steps and step-lift during horizontal walking 152
      Number of steps in horizontal walking 154
      Step-lift during horizontal walking 155
        Possible causes for variation in step-lift 155
        Total step-lift per minute 156
        Step-lift per step 157
      Energy increment due to work of step-lift 157

24616

PAGE.
Discussion of results—continued.
Experiments with horizontal walking—continued.
Physiological effects of horizontal walking.......... 160
Respiration-rate during horizontal walking.......... 160
Pulmonary ventilation during horizontal walking.......... 162
Pulse-rate during horizontal walking.......... 163
Comparison of pulse-rate during standing with that during horizontal walking.......... 165
Relationship of oxygen consumption, pulse-rate, and pulmonary ventilation during horizontal walking.......... 169
Body-temperature during horizontal walking.......... 172
Blood-pressure during horizontal walking.......... 175
Experiments with grade walking.......... 177
Physiology of mouth-breathing appliances.......... 177
Effect of mouthpiece breathing upon metabolism.......... 178
Effect of mouthpiece breathing upon respiration-rate, pulmonary ventilation, and rate of oxygen consumption.......... 182
Effect with subject standing.......... 184
Effect during grade walking.......... 184
Conclusions with regard to the effect of long and short preliminary mouthpiece breathing.......... 192
Metabolism of subjects walking on an incline.......... 193
Carbon-dioxide elimination and oxygen consumption during grade walking.......... 224
Respiratory quotient during grade walking.......... 230
Total heat-output during grade walking.......... 233
Increment in heat-output due to grade-lift.......... 238
Total increment in heat due to grade-lift.......... 238
Increment in heat per kilogrammeter of work done in grade-lift.. 241
Step-lift during grade walking.......... 243
Comparison of step-lift in horizontal and grade walking.......... 246
Work of ascent.......... 248
Efficiency in grade walking.......... 249
Efficiency in work due to grade-lift.......... 249
Efficiency in work of ascent.......... 253
Effect of lameness upon the efficiency of E. D. B.......... 256
Physiological effects of grade walking.......... 257
Respiration-rate during grade walking.......... 257
Pulmonary ventilation during grade walking.......... 260
Pulse-rate during grade walking.......... 262
Body-temperature during grade walking.......... 268
Blood-pressure during grade walking.......... 276
Physiological changes in transition from standing to grade walking and the reverse.......... 277
Respiratory changes in transition from standing to grade walking..... 278
Changes in respiration-rate.......... 279
Changes in pulmonary ventilation.......... 284
Changes in rate of oxygen consumption (unreduced).......... 284
Respiratory changes in transition from grade walking to standing.... 287
Changes in respiration-rate.......... 288
Changes in pulmonary ventilation.......... 293
Changes in rate of oxygen consumption (unreduced).......... 295
Conclusions regarding respiratory changes in transition from grade walking to standing and the reverse.......... 296
Pulse-rate in transition from standing to grade walking.......... 297
Pulse-rate in transition from grade walking to standing.......... 303
After-effects of grade walking.......... 305
Summary of results.......... 309

ILLUSTRATIONS.

PAGE.

FRONTISPIECE. Subject and apparatus in readiness for experiment.

FIG. 1. Treadmill, with spirometer and various recording devices 19

2. Double spirometer 22

3. Respiration counter 24

4. Electrical counter for recording number of respirations 24

5. Detail of valve-operating device and period counter 28

6. Framework used in determining the angle of ascent 29

7. Step-lift recorder 30

8. Typical records of pulse-rate as obtained with oscillograph and string galvanometer 34

9. Metabolism of E. D. B. in standing experiments without food 98

10. Increments in total heat-output over standing requirement for subjects walking on a level at different rates in meters per minute, with percentage increase for E. D. B. 146

11. Average energy cost per horizontal kilogrammeter of walking on a level at various distances per minute 148

12. Typical pulse-rate curves for E. D. B. and W. K. during standing and horizontal-walking experiments 166

13. Total heat-output, oxygen consumption, pulmonary ventilation, respiration-rate, and pulse-rate of E. D. B. and W. K., referred to horizontal kilogrammeters for experiments with subjects walking on a level at different speeds 170

14. Typical body-temperature curves for E. D. B. during periods of standing and periods of walking on a level at various speeds 173

15. Reproduction of kymograph records in mouthpiece experiments, with intermittent renewal of oxygen 183

16. Total carbon-dioxide production of T. H. H., H. R. R., and W. K., referred to kilogrammeters of work performed in walking on different grades 225

17. Total carbon-dioxide production of E. D. B. referred to kilogrammeters of work performed in walking on different grades 226

18. Total oxygen consumption of T. H. H., H. R. R., and W. K. referred to kilogrammeters of work performed in walking on different grades 227

19. Total oxygen consumption of E. D. B. referred to kilogrammeters of work performed in walking on different grades 227

20. Respiratory quotients of W. K. and E. D. B. referred to kilogrammeters of work performed in grade walking 230

21. Total heat-output of W. K. referred to kilogrammeters of work performed in walking on different grades 234

22. Total heat-output of E. D. B. referred to kilogrammeters of work performed in walking on different grades 234

23. Total oxygen consumption and heat-production of W. K. referred to kilogrammeters of work performed in grade walking 236

24. Total oxygen consumption and heat-production of E. D. B. referred to kilogrammeters of work performed in grade walking 237

25. Daily increments in heat-production over standing requirement and horizontal component referred to kilogrammeters of work done in walking experiments on different grades with W. K. 239

26. Daily increments in heat-production over standing requirement and horizontal component referred to kilogrammeters of work done in walking experiments on different grades with E. D. B. 239

27. Average increments in heat-production due to grade-lift in walking experiments with E. D. B. 240

PAGE.
FIG. 28. Pulse-rate, respiration-rate, and pulmonary ventilation of W. K. during grade walking, referred to kilogrammeters of work.................... 258
29. Pulse-rate, respiration-rate, and pulmonary ventilation of E. D. B. during grade walking referred to kilogrammeters of work.................. 259
30. Typical pulse curves of E. D. B., with subject standing, walking on a level, and walking on an incline 265
31. Typical pulse curves of E. D. B., with subject standing and walking on an incline.. 266
32. Typical pulse curves of E. D. B., with subject standing and walking on an incline.. 267
33. Typical body-temperature curves of E. D. B., with subject standing and walking on an incline.. 269
34. Typical body-temperature curves of E. D. B., with subject standing and walking on an incline.. 271
35. Typical body-temperature curves of E. D. B., with subject standing and walking on an incline.. 272
36. Typical body-temperature curves of E. D. B., with subject standing and walking on an incline.. 274
37. Contrasting curves of body-temperature of E. D. B., with subject standing and walking on an incline................................. 275
38. Typical kymograph records of respiration, pulmonary ventilation, and rate of oxygen consumption in periods of transition from standing to walking and the reverse.. 278
39. Duration of pulse-cycles of E. D. B., in transition from standing to grade walking, as indicated by average cycle duration for measured groups of 10 pulse-cycles.. 298
40. Duration of pulse-cycles of E. D. B., in grade-walking experiment of February 28, 1916, as indicated by averages of 2 pulse-cycles, measured individually.. 300
41. Duration of pulse-cycles of E. D. B., in grade-walking experiment of February 29, 1916, as indicated by averages of 2 pulse-cycles, measured individually.. 301
42. Duration of pulse-cycles of E. D. B. in transition from grade-walking to standing, as indicated by average cycle duration for measured groups of 10 pulse-cycles... 304

GASEOUS EXCHANGE AND PHYSIOLOGICAL REQUIREMENTS FOR LEVEL AND GRADE WALKING

INTRODUCTION.

This investigation was undertaken as a part of the larger plan formulated in the Nutrition Laboratory some years ago for the study of the energy requirements of the body during muscular exercise, including a consideration of the efficiency with which the human body can perform some of its more common daily tasks. The results of Atwater and Benedict,[1] obtained in experiments with the respiration calorimeter at Wesleyan University, demonstrated that the energy of the human body could be measured like that of any machine. Accordingly, when the Nutrition Laboratory was established in Boston, the plans for research included a continuation of this work, and a respiration calorimeter was constructed, which was designed especially for this type of experiment.

The results of the studies of Zuntz[2] and his associates on the gaseous exchange of the animal body demonstrate that the energy requirements can be found indirectly by computation from the oxygen consumption and the respiratory quotient with an expenditure of much less time and effort than is required for direct measurements by the respiration calorimeter. This has resulted in a diminishing use of the respiration calorimeter for the energy measurements of the human body, and the data reported in the following pages have been obtained by indirect calorimetry. However, it must not be overlooked that the respiration calorimeter first demonstrated that the law of the conservation of energy holds in the animal body and that for our knowledge of the values used in indirect calorimetry we depend on data obtained by direct calorimetric measurements.

The numerous comparisons of direct and indirect calorimetry made by Lusk and Du Bois in New York, with the calorimeter at the Russell Sage Institute of Pathology, as well as those made with the calorimeters at Wesleyan University and later at the Nutrition Laboratory, have shown that with severe muscular work the agreement between the results obtained by the direct and indirect methods is ideal for periods of 24 hours. During rest experiments the agreement has been shown to obtain for periods as short as one hour. The agreement in the short periods has not, however, been thus far demonstrated under conditions of excessive muscular work with accompanying alterations in body-temperature and the possibility of over-ventilation of the lungs, as well as possibilities of special metabolic cleavages, such as lactic acid.

---

[1] Atwater and Benedict, U. S. Dept. Agr., Office Exp. Sta. Bull. 69, 1899; *ibid*, Bull. 109, 1902; *ibid*, Bull. 136, 1903; Benedict and Milner, U. S. Dept. Agr., Office Exp. Sta. Bull. 175, 1907; Benedict and Carpenter, U. S. Dept. Agr., Office Exp. Sta. Bull. 208, 1909.

[2] Zuntz, Archiv f. d. ges. Physiol., 1897, 68, p. 201. See, also, Zuntz and Schumburg, Physiologie des Marsches, Berlin, 1901, p. 260.

In the research here projected it was definitely planned to conduct the experiments ultimately in a respiration chamber provided with calorimetric features. Since special stress was to be laid upon the measurements of ventilation of the lungs, body-temperature, heart-rate, and physiological factors other than the metabolism, it was deemed wisest first to carry out a series of experiments in which the subject walked upon a treadmill in the laboratory and was thus much more accessible than he would be when walking upon a treadmill in a respiration chamber. It is this series of experiments that is reported in this publication. The calorimeter for carrying out the work experiments planned has actually been constructed in the Nutrition Laboratory and thoroughly tested as to its capacity for measuring large amounts of heat as well as respiratory products. At the moment of writing it has not been used for experiments with men on the treadmill.

It is hoped that when full information is obtained of some of the fundamental requirements of the human body during periods of muscular exercise, scientists will be in a better position to consider the question from the standpoint of industrial efficiency, and that in the end it may be possible to state whether or not a laborer should be able to perform a given amount of work with a greater efficiency than is commonly done, that is, with less cost to the body economy. If such evidence is positive, the problem of training the laborer and determining in what way the energy is wasted will be the next and most obvious step, and the suggestions and criticisms of Frederick W. Taylor[1] would have the added support of physiological science. Mention should also be made here of the very clever mechanical devices of Amar,[2] who has already attacked the problem of efficiency in various kinds of work.

The results of two researches[3] made by this Laboratory as a part of the original plan have already appeared. The following pages present the results of further study which has been applied more especially to the work of grade walking. As a necessary accompaniment of a study of grade walking, observations were made with the subject walking on a level. These served the dual purpose of (*a*) supplying a suitable base-line for the proper study of the special factors involved in grade walking, and (*b*) supplementing to a not inconsiderable extent the present knowledge regarding the physiology of horizontal walking. Additional data have been collected on the changes in the pulse-rate, respiration-rate, the pulmonary ventilation, and body-temperature as affected by the intensity of the work in both horizontal and grade walking, and their relation to the energy expended.

---

[1] Taylor, The principles of scientific management, New York, 1911.

[2] Amar, Le moteur humain, Paris, 1914.

[3] Benedict and Cathcart, Carnegie Inst. Wash. Pub. No. 187, 1913; Benedict and Murschhauser, Carnegie Inst. Wash. Pub. No. 231, 1915.

RESEARCHES BY OTHER INVESTIGATORS ON ENERGY REQUIREMENTS FOR WALKING.

HORIZONTAL WALKING.

The earlier studies of the energy metabolism during horizontal walking have been reviewed by Durig[1] and by Benedict and Murschhauser.[2] One of the main subjects of interest in this work is the determination of the energy cost per horizontal kilogrammeter, i. e., the energy cost of the movement of 1 kilogram 1 meter in a horizontal direction. The earlier studies were made under various conditions of rest, food, altitude, speed of walking, and methods of computation as regards the basal value. In consequence, the results vary widely, Benedict and Murschhauser in their summary table noting average values ranging from 0.308 to 1.169 gram-calories per horizontal kilogrammeter. Durig showed that when the rate of walking was limited to moderate speeds and the subject was in the post-absorptive condition, the energy expenditure was very close to 0.55 gram-calorie per horizontal kilogrammeter, but when the speed exceeded a certain degree, given by Durig as approximately 80 meters per minute, the energy cost per horizontal kilogrammeter increased. This limiting speed Durig termed the "maximal economic velocity." Reichel,[3] in Durig's laboratory, gave a mathematical formula to this generalization, and Durig further states that for each meter in excess of the maximal economic velocity, the energy metabolized increases from 1.2 to 1.5 per cent of the normal value.

In continuation of Durig's work and employing his well-established methods, Brezina and Kolmer[4] conducted experiments on horizontal walking with and without load at varying velocities. In these studies the authors confirmed the results of Durig in relation to the absence of the effects of speed below the maximal economic velocity, and add that this value is independent of a load up to 21 kg., that is, a dead load of 21 kg. can be carried by the human body as economically as the same amount of live weight. Above either this load or the maximal economic velocity the energy metabolized per horizontal kilogrammeter increases. These authors further state that if a definite weight is to be transported it can be accomplished more economically by increasing the load than by increasing the velocity. As all these observations were made on but one subject (Brezina), the physiologically interesting problem as to the application of these general deductions to persons of widely differing weights remains to be settled.

---

[1] Durig, Denkschr. d. math.-natur. Klasse d. kaiserl. Akad. d. Wissensch., 1909, **86**, p. 250.

[2] Benedict and Murschhauser, Carnegie Inst. Wash. Pub. No. 231, 1915.

[3] See Durig, Denkschr. d. math.-natur. Klasse d. kaiserl. Akad. d. Wissensch., 1909, **86**, pp. 278 and 279.

[4] Brezina and Kolmer, Biochem. Zeitschr., 1912, **38**, p. 129.

Subsequently, Brezina and Reichel[1] made a study of these data of Brezina and Kolmer in an endeavor to express the relations between the increase in metabolism and the increase in load and in velocity. They give the results of their treatment of the data in the form of two generalizations, (*a*) that for moderate speeds the cost of 1 h. kg. m. is independent of the speed and is smallest for loads of approximately 19 kg., and (*b*) that the energy increase for loads above this maximum weight of 19 kg. is proportional to the square of the load difference. Expressed in terms of calories, the equation is $U=0.5+\frac{(L-19)^2}{10{,}000}$, in which U equals calories per horizontal kilogrammeter and L equals load in kilograms. Beyond the point of maximal economic velocity, the metabolism increases per horizontal kilogrammeter in geometrical ratio to the arithmetical increase in the speed.

Benedict and Murschhauser[2] for their two subjects found the energy requirement per horizontal kilogrammeter to be 0.507 and 0.493 gram-calorie, respectively, for speeds of approximately 75 meters per minute, that the energy requirements increased with the increase in speed, and that running at 147.5 meters per minute was more economical than walking at the same velocity. A measurement of the energy required for the elevation of the body due to the step-movement showed that, with a speed of 76 meters per minute, one of their subjects, weighing 73 kg., expended 0.65 calorie in this work, that is, 23 per cent of the increase in metabolism over the standing requirements was due to this work of step-elevation.

Waller,[3] in a series of reports on the physiological cost of various forms of muscular work, included a few experiments on horizontal walking. Computations show that his results for speeds of approximately 100 meters per minute yield somewhat over 0.8 gram-calorie per horizontal kilogrammeter. Running at a speed of approximately 200 meters per minute gave a heat-production of about 1.3 gram-calories per horizontal kilogrammeter. The first value is measurably higher than that usually found, and may in part be explained by the fact that, as Waller himself states, his method determines only the carbon-dioxide production, a respiratory quotient is assumed, and there is an acknowledged error of ±5 per cent. In general, his values run somewhat higher than those commonly accepted as a result of other walking experiments.

---

[1] Brezina and Reichel, Biochem. Zeitschr., 1914, **63**, p. 170.

[2] Benedict and Murschhauser, Carnegie Inst. Wash. Pub. No. 231, 1915, pp. 79 and 87.

[3] Waller, Journ. Physiol., 1919, **53**, Proc. Physiol. Soc., p. xxiv; see, also, Journ. Physiol., 1919, **52**, Proc. Physiol. Soc., p. lxxii.

Benedict, Miles, Roth, and Smith,[1] in the report of a study on the effects of restricted diet, include the measurement of the gaseous exchange during level walking on a treadmill of a group of 12 young men in normal condition and of the same group after 20 days of restricted diet. They likewise report the gaseous exchange during walking of a group of 11 men after they had been on a restricted diet for a period of 120 days. A special closed-chamber method was used, and the carbon dioxide produced and the oxygen consumed were determined by analysis of the chamber air. They found the average cost per horizontal kilogrammeter for the normal men to be 0.597 gram-calorie, and for the same group after 20 days of restricted diet 0.562 gram-calorie. For the group with a restricted diet for 120 days the cost per horizontal kilogrammeter was 0.522 gram-calorie, thus indicating a somewhat greater efficiency per unit of work for the men who were on a restricted diet and much below their usual body-weight. These figures, the authors state, were for brief periods of moderate speed (70 meters per minute) and do not apply to conditions in which continued exercise and stamina might be prime requisites.

Cathcart and Orr,[2] using the Douglas bag method, made a series of studies on the energy requirements for the various forms of exercise required of British recruits. Inasmuch as the experiments were carried out under various conditions of weather and terrain, the authors distinctly state that all they could expect to obtain was an average of the energy expended in performing any given type of drill. Among the many forms of exercise reported in their publication was included that of marching with light (15.3 kg.), medium (20.5 kg.), and heavy (25 kg.) loads. The speed was 91.4 meters per minute on a comparatively level and smooth stretch of road. For these conditions they found the cost per horizontal kilogrammeter to be 0.543, 0.638, and 0.672 gram-calorie for the several loads. In addition to these field tests, a series was also made on one of the authors wherein the details are more nearly those of the laboratory research in which the effects of diet and the effects of velocity and load were studied. Under these conditions they found an increased cost per horizontal kilogrammeter with increase in speed and load from approximately 0.52 gram-calorie for a speed of 57 meters per minute to 0.85 gram-calorie at a speed of 183 meters per minute with a load of 11 kg., and from 0.48 to 0.72 gram-calorie with a load of 26 kg. The last value was, however, for a speed of 110 meters per minute. They also found the average cost per horizontal kilogrammeter for three subjects walking with a 9 kg. load at speeds of 55, 82, and 110 meters per minute to be 0.48, 0.51, and 0.65 gram-calorie.

---

[1] Benedict, Miles, Roth, and Smith, Carnegie Inst. Wash. Pub. No. 280, 1919, p. 546.

[2] Cathcart and Orr, The energy expenditure of the infantry recruit in training. H. M. Stationery Office, London, 1919.

Liljestrand and Stenström[1] report a series of respiration experiments with the subjects either walking or running. These authors used the Douglas bag, with the men in the post-absorptive condition. The walking was done on a level track of oval form in the stadium at Stockholm. The distances walked were 100 meters, with a preliminary period of 1 minute or longer. Measurements for both the sitting and standing positions were also made. The investigators report their values as oxygen consumed per horizontal kilogrammeter. After deducting a resting value for sitting, they assumed a respiratory quotient and calculated for the subject N. S. (body-weight 80 kg.) an average cost per horizontal kilogrammeter of 0.517 gram-calorie for walking at a speed of 50 to 75 meters a minute. For a speed of 75 to 100 meters per minute the cost was 0.613 gram-calorie, and above 100 meters per minute it was 0.830 gram-calorie. For the subject G. L. (body-weight, 60 kg.) the energy cost at similar speeds was 0.491, 0.574, and 0.710 gram-calorie, respectively.

In their experiments with the subject running these authors found that the cost per horizontal kilogrammeter fell with the increase in speed. For the subject N. S., with a speed of from 144 to 175 meters per minute, the heat expenditure was 1.004 gram-calories per horizontal kilogrammeter. This fell to 0.796 gram-calorie for a speed between 225 and 250 meters per minute. Similar results were found with the subjects G. L. and E. S.

Cathcart, Lothian, and Greenwood[2] have considered the energy expended in relation to the velocity of walking and take exceptions to the generalization of Brezina and Reichel that the cost of movement remained constant up to a velocity of 80 meters per minute and thereafter increased geometrically. They contend that as a general physiological law it involves a discontinuity at a fixed point between the speed and the energy expenditure, and other evidence points to uneconomical work at low speeds. Furthermore, as an interpolation formula, they consider the data upon which it is based are insufficient, for although they cover a wide range of speed and load, they relate to but one subject. These authors, using the data of Brezina and Reichel, show that the relation between the energy cost per unit of time and speed may be represented with equally good approximations to the observed values by a formula differing from that of Brezina and Reichel. They conclude that neither their own formula nor that of Brezina and Reichel expresses a physiological law and that they are useful solely as interpolation formulæ. They also find that by applying their equation to some 150 experiments made at speeds of 55, 82, and 110 meters per minute, the optimum rate of walking was approximately 82 meters per minute, a value close to that found by Durig.

---

[1] Liljestrand and Stenström, Skand. Archiv f. Physiol., 1920, **39**, p. 167.

[2] Cathcart, Lothian, and Greenwood, Journ. Roy. Army Med. Corps, April, 1920.

General Considerations with Regard to Previous Researches on Horizontal Walking.

From the large mass of evidence obtained in European and American laboratories on the metabolism during horizontal walking, it can be seen that no little portion of it has been accumulated with the primary object of the transportation of loads. This has in part been necessitated by the technique employed in the Zuntz school of carrying on the back a rather cumbersome and weighty meter with its attachments, and in part by the fact that interest has been stimulated by Alpine touring. Certain fundamental experiments have been made in laboratories by means of treadmills. When a pack was not transported the results of these earlier experiments are perfectly comparable with those with free walking. They are, however, even at best, too few, and accumulation of further evidence is entirely justified.

Practically all of the results point towards the excellence of the work carried out under the supervision of Durig. Inherently, perhaps, no further investigation on horizontal walking *per se* is justifiable with the great number of other problems on walking which await solution. Durig's main problem was the study of the metabolism for the work of ascent, but unfortunately nearly all of his work included not only the transportation of a load but the use of a cumbersome, unweildy gas-meter carried on the back. That these conditions do not call into play a much larger degree of muscular coordination than would ordinarily be required in free walking is difficult to believe. On the other hand, it is clear that Durig's values for the energy required to transport 1 kg. a horizontal meter are closely in accord with the results of practically all the work done by other methods, although, as a rule, they run slightly higher, which would be expected from the nature of the technique.

Two important points must be considered: First, that for all investigations on grade walking, clearly established base-lines are necessary. These can best be obtained by actual test, i. e., by having the subject walk on a horizontal plane under exactly the same conditions as he subsequently walks on a grade. This particular factor influences in large part the accumulation of the material on horizontal walking to be given in the present report.

Secondly, evidence has been forthcoming, although unfortunately as yet not accompanied by clearly defined experimental proof, that walking in free, open air has a measurably different physiological effect from that of walking on a treadmill in a more or less closed laboratory. In any event, this effect must be relatively small in degree as compared to the effect of grade walking. Consequently, all contributions to technique or to the physiology of horizontal walking that will make the establishment of the normal base-line more definite are to be welcomed, for the problem of the difference in effect of walking in the open air as compared to walking on a treadmill in a well-ventilated room can only be solved by the use of impeccable technique.

GRADE WALKING.

The majority of the studies which involve grade walking have been made in connection with studies of the effects of high altitudes upon the physiological actions of the human organism. The conditions of high altitudes, mountain paths, and, in many cases, a previous diet, must be taken into consideration in examining the results. In preparation for these mountain expeditions, nearly all the researches included a series of treadmill experiments which alone are really comparable with our results. Most of the results in these experiments were obtained by the Zuntz method. With this method the subject breathes through suitable valves, the volume of air is measured, and its composition determined by analysis of carefully drawn samples. From the known heat value of a cubic centimeter of oxygen or carbon dioxide for the respiratory quotient found, the energy expended per unit of time is then calculated.

The basis for comparison was the carbon-dioxide production, the oxygen consumption, or the heat expended per kilogrammeter of work done by the subject in lifting his body-weight, plus any loads he carried in the form of equipment, such as gas-meter, etc., to the elevation attained by the grade, or briefly, the work of the "grade-lift." The question of the proper base-line has been variously treated. The resting or maintenance metabolism in either the lying or the standing position has been universally deducted from the total gaseous exchange measured, but the allowance for the so-called "horizontal component" has been variously regarded. It is more generally estimated as equivalent to an equal linear distance found from horizontal-walking experiments. In other cases, no allowance has been made for this factor, but the energy expended per meter of distance walked and kilogrammeter of lift is reported.

In 1891, Katzenstein[1] made some measurements of the gaseous metabolism during grade walking in the laboratory of Zuntz in Berlin, employing a treadmill and the Zuntz method of measuring the gaseous exchange. Four subjects were used and the basal metabolism and the metabolism during horizontal walking were determined. The grade of the treadmill was of moderate pitch, varying from approximately 10 to 13 per cent. As computed from the respiratory quotients, the heat-output was 5.69 to 7.33 calories per kilogrammeter, with efficiencies of 31.9 to 41.1 per cent. The great variations in the results of Katzenstein are in no small part due to the wide differences in his estimations of the oxygen consumption per horizontal kilogrammeter, which ranged from 0.0858 c. c. for his subject Zimm to 0.1682 c. c. for his subject Krzywy, and also to the fact that the relatively low grade of the treadmill did not produce a large amount of work.

---

[1] Katzenstein, Arch. f. d. ges. Physiol., 1891, **49**, p. 330.

In the same year Gruber[1] made a study of the effect of training in the ascent of approximately 80 meters to the Münster tower outside of Berne. The experiments were made after a midday meal, and the carbon-dioxide production alone was determined by a gravimetric method. The results are primarily of interest as implying increased efficiency following training.

Schumburg and Zuntz,[2] in a study of the effects of high altitudes, report a series of experiments with Zuntz walking on a treadmill in Berlin at a grade of 31 per cent and a speed of 24 meters per minute, in which the average oxygen consumption per kilogrammeter of work done was 1.77 c. c., or an efficiency of 27 per cent. With Schumburg as the subject, the oxygen consumption was 1.73 c. c., with an efficiency of 28 per cent. Later, these two men, when walking up a grade of 31 per cent on Monte Rosa, found their efficiencies to be 20.9 and 23.2 per cent.

A. and J. Loewy and L. Zuntz,[3] preliminary to their expedition to Monte Rosa, made a series of measurements on a treadmill in Berlin at grades of about 23.0, 30.5, and 36.6 per cent. The energy production per kilogrammeter of grade work, after the resting value and the value for the horizontal component had been deducted, varied from 6.74 to 8.07 calories per kilogrammeter for A. L., 6.53 to 7.30 calories for J. L., and 6.41 to 7.32 calories for L. Z., with efficiencies from 29 to 36.5 per cent. The lowest efficiency was found with A. L. and the highest with L. Z.

In the expedition on Monte Rosa made by these investigators, in walking up grades of 26 to 33 per cent at Col d'Olen with an elevation of 2,840 meters, and at Capanna Gnifetti, with an elevation of 3,620 meters, the metabolism per kilogrammeter of work due to the grade walking was as follows: For A. L., 8.13 and 9.11 calories per kilograms meter; for J. L., 8.23 and 8.99 calories; for L. Z., 8.77 and 8.41 calories. The efficiencies were: For A. L., 28.8 per cent at Col d'Olen, and 25.7

---

[1] Gruber, Zeitschr. f. Biol., 1891, **28**, p. 466.

[2] Schumburg and Zuntz, Arch. f. d. ges. Physiol., 1896, **63**, p. 461.

[3] A. and J. Loewy and L. Zuntz, Arch. f. d. ges. Physiol., 1897, **66**, p. 477.

per cent at Capanna Gnifetti; for J. L., 28.4, and 26.0 per cent; and for L. Z., 26.7 and 27.8 per cent, respectively.

Bürgi,[1] in a study on the effects of training, made ascents of 25 per cent grade at Brienz (734 meters) and the Rothorn (2,184 meters); also on the Gornergrat, where the grade was 19.3 per cent and the height 2,987 meters. The carbon dioxide only was determined in these experiments.

From Bürgi's results, Durig[2] has computed the energy required per kilogrammeter of grade work, using an assumed respiratory quotient of 0.80, and found it to be 8.6 to 9.8 calories at Brienz, 10.2 to 12.3 calories on the Rothorn, and 9.3 calories on the Gornergrat. After training the expenditures were lower.

Frentzel and Reach,[3] in their study on the source of muscular power reported some experiments in which the subject walked on the treadmill with a grade of 23 per cent. These experiments, however, were not made with the man in the post-absorptive condition, but after a special diet of carbohydrates, proteins, or fats. From the data for the gaseous exchange the computed efficiencies are 36.4 for F. and 35 per cent for R.

Zuntz and Schumburg,[4] in their comprehensive study of marching, included a few experiments on grade walking. These, however, were made with a grade of only 6.5 per cent. We have computed an efficiency from their data of 31.2 per cent.

Durig and Zuntz[5] give the energy expended by themselves when walking on the glacier of Monte Rosa as 14.65 and 9.76 calories per kilogrammeter of work. The low efficiencies are obviously attributable to the poor footing.

Durig,[6] in 1906, made some grade studies upon himself 1½ to 2 hours after a light breakfast, when walking with a load of 18 kg. on the Bilkengrat at grades of 25 to 27 per cent. In all, 33 experiments were reported, showing an efficiency of 25.6 to 29.8 per cent. The average expenditure was 7.9 calories and the average efficiency 29.5 per cent. Durig found that the efficiency increased with practice. He also found a greater metabolism in the first periods of the day, indicating need of practice for each day, that the path conditions had little effect, and that the respiratory quotient had a tendency to fall.

In 1901, Zuntz and his colleagues, A. Loewy, Müller, and Caspari,[7] spent the summer upon Monte Rosa, where elaborate studies were carried out for which preparations had been made during the previous winter. The report includes the gaseous exchange of the four authors and two others during grade walking in treadmill experiments in Berlin, and also on the railroad up the Rothorn, at Brienz, on Col d'Olen, and for a few experiments at the Gnifetti-Hütte on Monte Rosa. Table 1 gives the computed percentages of efficiency for walking on the different grades in these experiments.

---

[1] Bürgi, Arch. f. Anat. u. Physiol., Physiol. Abth., 1900, p. 509.

[2] Durig, Denkschr. d. math.-natur. Klasse d. kaiserl. Akad. d. Wissensch., 1909, **86**, p. 300.

[3] Frentzel and Reach, Arch. f. d. ges. Physiol., 1901, **83**, p. 477.

[4] Zuntz and Schumburg, Physiologie des Marsches, Berlin, 1901.

[5] Durig and Zuntz, Travaux de l'année 1903, Laboratoire scientifique international du Mont Rosa, Turin, 1904, p. 65; also Arch. Anat. u. Physiol., Physiol. Abth., 1904, Suppbd., p. 417.

[6] Durig, Arch. f. d. ges. Physiol., 1906, **113**, p. 213.

[7] Zuntz, Loewy, Müller, and Caspari, Höhenklima u. Bergwanderungen, Berlin, 1906.

TABLE 1.—*Percentage of efficiency in grade-walking experiments made by Zuntz and Durig, and their colleagues.*

Subject.	Treadmill, Berlin, 12.7 p. ct.	Brienz (500 meters), 25 p. ct.	Rothorn (2,100 meters), 25 p. ct.	Col d'Olen (2,900 meters), 45 p. ct.	Monte Rosa (3,700 meters), 22 p. ct. (ca.).
Zuntz and colleagues:					
Waldenburg..	32.4	29.8	32.1	27.0	....
Kolmer......	[1] 46.5	42.7	41.9	....	17.7
Caspari......	33.1	33.8	32.1	....	19.8
Müller.......	38.6 [1]29.3	31.8	29.5	37.6	....
Loewy.......	43.3	32.7	32.5	....	....
Zuntz........	42.6	38.0	33.6	....	[1] 22.6

Subject.	Treadmill, Vienna, 21.6 p. ct.	Neuwaldegg (summer), 16.4 p. ct.	Neuwaldegg (winter), 16.4 p. ct.	Monte Rosa, 15.5 p. ct.
Durig and colleagues:				
Durig........	34.9 [1]34.1	31.1	24.0	21.2
Kolmer......	....	30.3	20.9	18.5
Rainer.......	....	31.7	15.2	21.5
Reichel......	....	30.1	21.8	19.8

Durig,[2] in the report of his expedition to Monte Rosa, presents a critical view of the preceding studies and also gives the results obtained by himself and his companions, Kolmer, Rainer, and Reichel, at Vienna and on Monte Rosa. The computed percentages of efficiency for these experiments are also included in table 1. Like the preceding work of Durig, these studies were carried out by the Zuntz method, with all of the Durig refinements. Durig notes, in comparing the experiments with himself on the treadmill and while walking on the Neuwaldegg outside of Vienna, that the walking on the treadmill was apparently done with less expenditure of energy than walking in the open. He also finds that, within the speeds walked, the rate of walking had but slight effect on the metabolism per kilogrammeter. He was unable to detect any increasing effect of the grade, but the condition of the path had a marked effect in lessening the efficiency. Durig lays considerable emphasis in this report upon the question of the basal value to be used. He questions the correctness of the procedure of deducting a value for a horizontal component based upon results found in horizontal-walking experiments, which necessarily assumes that the expenditure of raising the body at each step in horizontal walking is the same as for grade walking, although he computed the energy cost for grade walking by this method. Undoubtedly, as Durig suggests, the greatest error in all the efforts to study the energy cost per kilogrammeter of grade-lift lies in assessing the value for the horizontal component.

---

[1] Grade on treadmill: Kolmer, 18.2 p. ct.; Müller, 2d period, 26.2 p. ct.; Durig, 2d period, 14.7 p. ct.; Zuntz, on Monte Rosa, grade, 28.8 p. ct.

[2] Durig, Denkschr. d. math.-natur. Klasse d. kaiserl. Akad. d. Wissensch., 1909, **86**, p. 294.

A comprehensive and thorough study of the energy expenditures of grade walking, *per se*, was carried out by Brezina and Kolmer[1] in Durig's laboratory with a motor-driven treadmill which could be adjusted to various grades and speeds. In addition to the level walking experiments, experiments were made with the subject walking on grades of 4.7, 10.0 (ca.), 18 (ca.), 27.9, 35 (ca.), 39, and 42 per cent, while the total weights moved, including loads, were 70, 84, 93, 104, 114, and 124 kg. The speed of walking varied with the grade and the load, but the range was approximately 18 to 45 meters per minute. Naturally the lowest speeds were used on the higher grades. The method used in determining the basal metabolism was that of Zuntz, but the gas-meter was not carried on the back. The experiments were made with Brezina as the subject and in the forenoon, 1½ hours after a breakfast consisting only of a cup of sweetened tea. In the calculation of the results, an average basal metabolism of 1,083 gram-calories per minute was deducted, this being derived from earlier experiments with Brezina. For the level walking they found an average value of 0.51 gram-calorie per horizontal kilogrammeter. The maximum amount of work done was at a grade of 27.9 per cent, when a weight of 104.5 kg. was moved at a speed of about 30 meters per minute. This produced 900 kg. m. of work, with an energy output above the basal of 10,000 gram-calories per minute. Brezina and Kolmer found a considerable variation in the respiratory quotients, but on the whole the increases obtained depended upon the amount of work done. In the experiments when the larger amounts of work were performed, the respiratory quotient was found to be as high as 0.98 and there were many experiments with a quotient over 0.95.

The results of Brezina and Kolmer are further discussed by Brezina and Reichel,[2] who consider the data from a mathematical standpoint. These authors had previously shown[3] that the energy factor for the movement of 1 kg. 1 meter in horizontal walking within the range of the maximal economic velocity was not materially affected by loads up to 36 kg. and had derived a formula to express this generalization. Assuming that, according to their findings, the metabolism per horizontal kilogrammeter is independent of the speed and that the same relation exists for loads in grade walking as is found in level walking (an assumption which they were not able to confirm), they derived a formula which they believe expresses in approximate form the energy metabolized per kilogrammeter of total weight and meter distance covered between grades of 0 and 35 per cent. They find the optimum condition to be at a grade of 19.8 per cent, with a load of 19 kg., which required an expenditure of 10.1 calories for each kilogrammeter of grade-lift, or an efficiency of 23.1 per cent. It should be mentioned in this connection that Brezina and Reichel do not obtain net efficiencies, since they do not deduct the energy for the horizontal component, but compute the energy from the heat expended over the lying requirements.

---

[1] Brezina and Kolmer, Biochem. Zeitschr., 1914, **65**, p. 16.

[2] Brezina and Reichel, Biochem. Zeitschr., 1914, **65**, p. 35.

[3] *Ibid.*, **63**, p. 170.

Brezina and Reichel find that for the limited speeds used the rate of walking was without influence upon the energy per kilogrammeter, and also that the total energy per kilogrammeter of grade-lift for grades between 10 and 40 per cent with superimposed loads of from 3 to 56 kg. varied from 10.1 (the optimum value) to 12.4 calories, while for lower grades of 2.5 to 7.5 per cent, the measurements were as high as 29.3 calories. This large difference was undoubtedly due to the fact that the work at these low grades was too small a proportion of the total energy metabolized to be accurately determined. Brezina and Reichel give the data somewhat extensive mathematical treatment and derive certain formulæ which, in their judgment, make it possible to calculate the increase in energy due to the load and the grade, provided certain limits of speed and load are not overlooked. They likewise include the efficiency as a constant function of the grade.

The work of Brezina and his associates Kolmer and Reichel is by far the most extensive and painstaking of any of the studies on the physiology of walking, and their conclusions are suggestive. But, as they themselves say, though the study was carried out over a considerable range of speed and grade, the data represent the results of experiments with only one subject and considerably more data are required before their generalizations can be universally accepted.

In physiological experimenting the use of but one subject has frequently been the basis of much adverse criticism of a piece of work. It is true that if but one isolated physiological factor is to be measured, this criticism is a serious one. In a study in which so complicated a process as the energy requirements of walking is concerned, the results of a careful series of experiments like those of Brezina and Kolmer, even when but one man is used for a subject, may properly be employed for extensive generalizations, until deviations with other subjects are proved. While, therefore, we are in full accord with the criticisms of Cathcart, Lothian, and Greenwood, previously referred to, we still are disposed to consider a series of experiments, such as those made with Brezina, of most fundamental importance in the progress of our knowledge of the physiology of walking. Indeed, in our experiments the importance of contributing further observations on a number of individuals has played a not unimportant rôle in planning the research.

Although Amar[1] reported a number of experiments in which the subject was engaged in horizontal walking, we have found in his studies but two with grade walking. These were made with one subject walking on an 8 per cent grade and again on a 13 per cent grade, with and without a superimposed load of 7.3 kg. The experiments are but briefly reported and the data do not lend themselves to an extensive computation of the efficiency.

In 1912, Douglas, Haldane, Henderson, and Schneider,[2] in an expedition to Pike's Peak, made an extensive series of horizontal-walking experiments which included two grade-walking observations, in which the gradient was 1 in 4, and the speed from 2 to 2.25 miles per hour. The special conditions of altitude, diet, and terrain make the results difficult of comparison with others.

Waller[3] has made some estimates of the mechanical efficiency shown by men in ascending a staircase while breathing into a Douglas bag. The total volume of air exhaled and the carbon dioxide produced were determined in these experiments. By assuming a respiratory quotient of 0.85, Waller computed the energy expended during the work and believes that ±5 per cent was the range of error by this method. He reports data for 12 subjects varying in age from 18.5 to 63 years and in weight from 54.5 to 98 kg., who made the ascent of a 20-meter staircase at an average efficiency of 33 per cent.

Waller and de Decker[4] report an average mechanical efficiency of 32 per cent for T. R. P. in five ascents of the staircase. Later, in a comparison of bicycle with staircase ergometry,[5] 17 experiments with A. D. W. showed efficiencies varying from 24.8 to 41.6 per cent for the staircase work. A complete report of this work of Waller has not yet appeared, but the results thus far published indicate very wide variations.

Magne[6] has recently made a study of the changes in the energy expenditure in walking due to alterations in the number and length of the steps. By means of a rubber bag and a Tissot mask, the air expired during the experimental period was collected and samples analyzed. The subject was in the post-absorptive condition and walked with a carefully controlled frequency and length of step both on a level and on grades of approximately 5, 10, and 15 per cent. Magne found that the minimum net expenditure for a given distance on a level was obtained at an approximate speed of 63 meters per minute, and the average net efficiency for the grade experiments was not far from 20 per cent.

---

[1] Amar, Le moteur humain, Paris, 1914, p. 507.

[2] Douglas, Haldane, Henderson, and Schneider, Phil. Trans. Roy. Soc. London, 1913, ser. B, **203**, p. 185.

[3] Waller, Journ. Physiol., Proc. Physiol. Soc., 1919, **52**, p. lxxii.

[4] Waller and de Decker, Journ. Physiol., Proc. Physiol. Soc., 1919, **53**, p. xxx.

[5] *Ibid.*, p. xliv.

[6] Magne, Journ. de physiol. et de path. gén., 1920, **18**, p. 1154.

General Considerations with Regard to Previous Work on Grade Walking.

The technical difficulties necessary to be overcome in a study of grade walking are so great that only those who have had actual experience in such experiments are in a position to criticize fairly the work of others. The historical development of the method of studying metabolism during severe muscular work, not only that of walking but likewise of other forms, such as bicycle riding, has gradually led to a perfection of the technique. In reviewing the earlier work, it is noticeable that the criticism that applied to the horizontal-walking experiments applies with even greater force here, namely, that it became necessary in many series of experiments to work under somewhat disadvantageous conditions.

The dry gas-meter method, which has been used in so large a proportion of the earlier studies, has one great disadvantage in that no experiments can be made without a load. The carrying of a pack is to be expected in walking, and particularly in Alpine work, but the transportation of an apparatus such as a gas-meter and accessories, weighing many kilograms and attached to the back, even though in the most approved manner, still presents a problem in equilibrium that is attained only with considerable practice. While it is true that the transportation of loads is of great economic importance in industrial operations, and a knowledge of the efficiency in transporting loads is thus essential, yet thousands of people walk each day without a load in comparison with the individual with a load; consequently, observations which can be obtained on individuals not carrying loads are, we believe, of general interest.

The modern method of substituting either a Douglas bag or a treadmill with a stationary meter is much to be preferred to the gas-meter method, provided essential differences between the work of walking in a well-ventilated room and that of walking in the free and open air on an equally even or satisfactory path are not subsequently developed. The Douglas-bag method is certainly a step in the right direction, inasmuch as the load is almost imperceptible. Unfortunately, relatively few experiments have as yet been carried out with this method, and many of these have been hastily made and without the careful attention to technical detail given in experiments with other types of apparatus.

Our own justification for making a study of the respiratory exchange in grade walking was, as stated earlier, the fact that it should serve in large part as a preliminary to a research upon grade walking in which direct calorimetry would be employed. The pronounced alterations in the respiratory quotient with severe labor, resulting in quotients at times appreciably over 1.00, make it a fair question as to whether or not the methods of indirect calorimetry give true indices of the actual heat-production under these conditions. Admittedly, the technical details to be overcome in making a study by direct calorimetry of the energy output of a man walking nearly to the limit of human endurance are very great, but it is believed that they may be overcome. In an effort to improve much of this technique, prior to inclosing the man in a hermetically sealed chamber, the treadmill experiments reported in the following pages were carried out at the Nutrition Laboratory.

PLAN OF STUDY.

The primary object of the experiments in this research was the determination of the energy expended by the human body in performing the work of lifting itself to a definite elevation by walking up-grade. With a treadmill of unusual design and accuracy, a respiration apparatus capable of measuring an oxygen consumption of 3,000 c. c. per minute and over with great rapidity and exactness, much accessory apparatus for studying physiological factors, such as respiratory volume, respiration-rate, pulse-rate, step-lift, etc., it was believed that opportunity was afforded for a contribution to the general physiology of horizontal walking, also, which would amply justify the additional labor. As previously stated, it was at the outset considered that this whole research was preliminary to a subsequent study in which direct calorimetry would be employed.

The total energy that is expended by the human body during grade walking is the sum of several factors, among which are (1) the energy required to maintain the vital functions, such as respiration and circulation, while the body is at rest, which may be termed basal energy; (2) the energy required for the muscular movements of the simple act of walking on a level; (3) the energy required to lift the body through a vertical distance corresponding to the elevation attained in the grade walking. Since the measurements of the metabolism in the grade-walking experiments reported in this publication represented the total energy expended, it was necessary to know both the basal-energy cost and the cost of horizontal walking to obtain the energy cost of the work of elevation.

Three groups of experiments were therefore carried out: (1) standing experiments, in which determinations were made of the energy expended while the subject was standing quietly without support, these values being taken in the computations as the "rest" requirement; (2) horizontal-walking experiments with measurements of the energy output at different speeds of walking; from these the energy expended in excess of the "rest" requirement was found, and thus the cost of moving 1 kg. of body-weight 1 meter on a level was determined; (3) grade-walking experiments from which the energy expended per kilogrammeter of vertical lift in excess of the rest and horizontal-walking requirements was calculated for the different grades and speeds with the efficiencies for each condition.

It was the intention to have the subject walk at certain definite rates in order that level and grade walking might be compared at the same speeds. Technical difficulties in the precise regulation of the speed of the treadmill made strict duplication too exacting a task in many instances and the results are consequently grouped according to the speeds which fell within limits of 5 meters per minute of each other. The grades were more easily maintained in the range between 2.5 to 45 per cent in rates of 5 per cent increase. It would have been desirable to have made both standing and horizontal-walking tests on each day that the grade-walking experiments were made; since, however, it was impossible to make experiments with a sufficient number of periods in each of the three groups, the only alternative was to secure an average value for both the standing and the horizontal-walking experiments.

The data obtained during the horizontal-walking experiments, besides supplying the energy factor per horizontal kilogrammeter used in computing the energy to be deducted from the values for the grade-walking experiments, allow a comparison of this factor with that reported by other investigators, and we believe they present in themselves a substantial addition to our knowledge of the physiology of walking. They also provide additional information as to the effect of the speed of walking upon the energy required per horizontal kilogrammeter, which has been reported to be practically independent of the speed for rates less than 80 meters per minute.

Another element contributing to the work performed in either horizontal or grade walking in addition to the three factors previously mentioned is the elevation of the center of gravity of the body as it moves forward with each step. This elevation of the body represents a positive and appreciable amount of work. An effort has been made to determine this elevation, or "step-lift," and to express it in terms of kilogrammeters of work. The proportion of increase in the energy due to this factor in horizontal walking may thus be obtained. If, in the grade experiments, the work due to the step-lift is added to the work of the vertical lift of the grade, the sum represents what may be called the total "work of ascent."

In addition to these primary measurements, the experimental conditions were favorable for collecting data on other physiological factors, and some results are presented on the changes in the respiration-rate and pulse-rate, the pulmonary ventilation, and rectal body-temperature which accompany the changes in the amount of work performed. A few observations on the changes in the blood-pressure between rest and exercise were made for comparison with the changes in the amount of work being done.

The readiness with which the heart and lungs respond to the changing demand of the body when work was either begun or ceased was also studied. The adaptability of the body to new demands—at times, a demand approximating the limit of human endurance, necessitating an oxygen consumption of over 3,000 c. c. per minute—is a factor in human economy that has been hitherto too little studied. The rapidity of adjustment after most strenuous exercise is of utmost importance in estimating "fitness" for the work performed. These experiments have been referred to as "transitional" experiments, and by measuring the oxygen consumption, ventilation, pulse-rate, and respiration-rate for successive fractions of a minute until either the normal or an approximately constant rate was obtained, the relation between the response of these physiological processes to the amount of work performed was obtained.

METHODS OF MEASUREMENT.

The group of apparatus used in this research was, in principle, that employed and described by Benedict and Murschhauser,[1] but with modifications essential for the increased amount of work to be performed. The principal apparatus employed were the universal respiration apparatus for determining the gaseous metabolism and the treadmill for the measurement of the muscular work. In addition, accessory apparatus were used for securing data on the pulse-rate, pulmonary ventilation, body-temperature, etc., which were not obtained by Benedict and Murschhauser in their study. The general arrangement of the apparatus, with subject in position for an actual experiment, is shown in the frontispiece and, in part, in figure 1.

---

[1] Benedict and Murschhauser, Carnegie Inst. Wash. Pub. No. 231, 1915, p. 29.

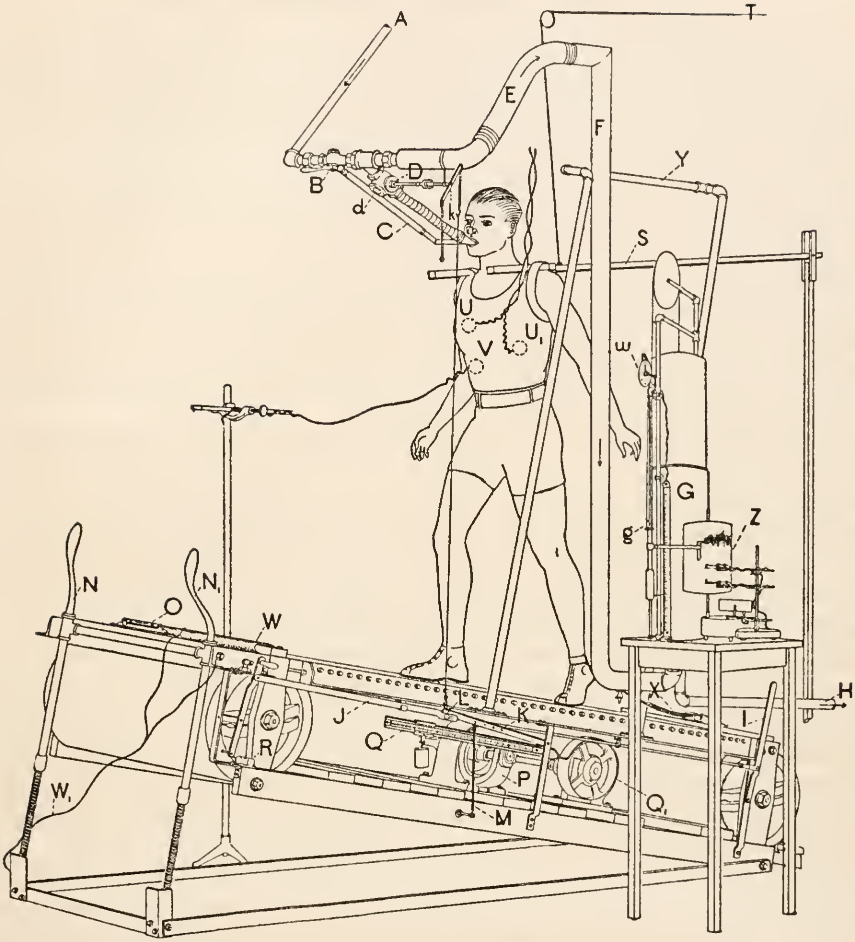

FIG. 1.—Treadmill, with spirometer and various recording devices.

The circulating air from the soda-lime containers of the respiration apparatus was conducted to the subject through the pipe *A*, and after passing through the pipes *E* and *F* and the spirometer *G*, was returned to the absorbers through the pipe *H*. Preliminary to the experiment, the subject respired into the room air through the 3-way valve *D* by the port *d*. At the beginning of the period, the valve *D* was turned and the subject was connected with the circulating-air system. By means of the by-pass *B*, the circulating air could be deflected through *C* and brought closer to the mouth of the subject, thus eliminating rebreathing. The parts of the apparatus specially indicated in the figure are: *E*, rubber hose to permit the adjustment of the mouthpiece to any height needed by the subject; *G*, spirometer with ventilation adder-wheel *w* and kymograph *Z; g*, pulley for reducing the movement of the pointer recording on the kymograph drum; *I*, lever for operating valve *D* by the bar *J*, connected by cord with arm *k; L*, knob supporting the arm *K; M*, tension spring for operating valve *D; N*, N_1, screws for adjusting the grade of the treadmill; *O*, spirit-level; *P*, motor, driving mechanism not shown; *Q*, Q_1, adjustable brake on the motor shaft; *R*, counter for recording revolutions of front pulley; *S*, long wooden fork fastened to the shoulders of the subject by elastic webbing; the rise and fall of this fork is transmitted by *T* to the step-lift counter and kymograph, not shown in the drawing; *U*, U_1, electrodes for securing electrocardiograms of the pulse-rate; *V*, electrode for grounding the subject; *W*, W_1, brass-gauze brush and leads for grounding the treadmill; this brush was discarded when the method was changed to that of grounding the subject by the electrode *V; X*, step-counter with spring attached to the subject's ankle; *Y*, framework protecting the spirometer.

UNIVERSAL RESPIRATION APPARATUS.

The universal respiration apparatus in its various adaptations has been frequently described in the publications from this Laboratory.[1] Briefly stated, it consists of a closed ventilating air-circuit, with provisions for a moderate degree of expansion in the air-volume and connection with the subject by means of a mouthpiece or nosepiece. The air is kept in motion by a rotating ventilator or blower, actuated by an electric motor, which forces the expired air through absorbents for moisture and carbon dioxide and returns it to the subject for rebreathing after the air has been moistened and the oxygen deficit has been made up from an oxygen-supply connected with the system and metered. Sulphuric acid is used for the water-absorbent and moist soda-lime for the carbon-dioxide absorbent. The combined increase in the weight of the soda-lime containers and the supplementary water-absorber gives data for calculating the volume of carbon dioxide expired by the subject. The amount of oxygen consumed is determined from the readings of a calibrated integrating meter connected with the oxygen-supply. The absorbing system, mounted on a two-shelved table, is in duplicate, with suitable valve connections which permit the use of either series of absorbers at will.

Since the amount of work to be performed was greater than in the study made by Benedict and Murschhauser, the ventilating system was equipped with a larger motor and driving-pulley. The speed of the one-sixth horse-power electric motor employed was controlled by a rheostat, fixed upon the front of the table, which permitted the variation of the ventilating air-current between 65 and 100 liters per minute. The two sulphuric-acid containers, or "Williams bottles," which were inserted in the system next to the blower, each had a capacity of 2.5 liters and were followed by a train of two large soda-lime containers for the absorption of the carbon dioxide, and a third large Williams bottle or air-drier for absorbing any moisture carried over from the moist soda-lime.

Moistener.—The dry air, after it left the carbon-dioxide absorbers, was moistened by passing it through water contained in a large Williams bottle. None of the subjects complained that the air was too dry. A test was made of the percentage of humidity by inserting a psychrometer in the air-circuit, and an average figure of 70 per cent was found when the rate of ventilation was highest. This figure has been used in reducing the volume of the pulmonary ventilation to standard conditions.

Spirometer.—In the research of Benedict and Murschhauser, a rubber bathing-cap was used as a tension equalizer for fluctuations in the volume of air in the closed circuit.[1] In the present research, a large spirometer (*G* in figure 1) was employed, 8 liters in capacity, which was built on the principles already described in reports from this Laboratory.[2] This spirometer was placed on a small table at the left of the treadmill and close to the subject. A light, non-viscous oil was used in the spirometer rather than water. None of the subjects complained of odor from the oil; in fact, none of them knew that oil was used.

---

[1] Benedict, Deutsch. Archiv f. klin. Med., 1912, **107**, p. 156; Benedict and Cathcart, Carnegie Inst. Wash. Pub. No. 187, 1913, p. 27; Benedict and Murschhauser, Carnegie Inst. Wash. Pub. No. 231, 1915, p. 31; Carpenter, Carnegie Inst. Wash. Pub. No. 216, 1915, p. 21.

During the experiments, when severe muscular work was being performed, the respirations of the subject became so deep that the movements of the spirometer-bell were too large to be recorded on the usual kymograph-drum. To reduce the movement of the pointer, the thread supporting the bell was passed through a pulley to which the counterpoise and the pointer were attached. (See *g*, fig. 1.) The movement of the pointer was thus reduced one-half, but this had its disadvantage in that it doubled any error in the reading, since all readings must be multiplied by 2. As in the walking experiments, the oxygen consumption was frequently 8 to 10 times the resting value, this doubling of the error played no rôle save in the "rest" experiments.

In measuring the rate of oxygen consumption in certain tests in this research, no oxygen was admitted for a portion of the experimental period and the lower capacity limit of the spirometer was thus reached in a few minutes. For these few tests, use was made of the double spirometer shown in figure 2. A duplicate spirometer *A* is attached to the principal one *B* by a large tube *E* and a 3-way valve *D*. The oxygen is introduced by means of the connection *C*. Both spirometers were filled with pure oxygen before an experiment, and the usual readings taken on the main spirometer *B*. As soon as the subject was connected with the ventilating system, the bell of the spirometer *B* fell rapidly with each respiration as the oxygen was consumed. When the oxygen was at as low a level as seemed wise, the three-way valve *D* was opened and oxygen from the duplicate spirometer *A* was forced into *B* by pushing down the bell of *A*. The valve was then closed and *A* was again filled from the oxygen cylinder through the connection *C*. This was repeated as often as necessary. The kymograph curve thus shows a succession of hills and valleys (see fig. 15, p. 183), due to the fact that the pointer rose on the scale of *B* as the oxygen was consumed and then sank when the supply from the reservoir *A* was forced into the main spirometer *B*. The time of filling spirometer *B* was scarcely 2 seconds, and not over one or two respiration tracings were lost in the process.

---

[1] Benedict, Am. Journ. Physiol., 1909, **24**, p. 345. See, also, Carpenter, Carnegie Inst. Wash. Pub. No. 216, 1915, p. 24.

[2] Benedict, Deutsch. Archiv f. klin. Med., 1912, **107**, p. 172; Carpenter, Carnegie Inst. Wash. Pub. No. 216, 1915, p. 37.

Pressure conditions.—The large volume of air being forced through the air-purifying system by the rapidly moving blower created considerable pressure in the system, and a small mercury manometer was introduced at the head of the absorber table immediately in front of the soda-lime bottles to act as a safety-valve in case of need. The pressure indicated by this manometer when the blower was delivering air at the rate of 100 liters per minute was from 130 to 180 mm. of mercury, depending upon the condition of the soda-lime and the amount of acid in the Williams bottles. From the absorber table to the valve of the mouthpiece, a $\frac{3}{4}$-inch galvanized-iron pipe was used and all joints, where practical, were soldered to reduce possibilities of leaks when there was a high pressure on the system. On the return line from the valve to the spirometer (see *F*, fig. 1) the pipe was 6 cm. in diameter, ordinary galvanized-iron conductor-pipe being used for the most part. This reduced the pressure so that just beyond the mouthpiece water manometers showed a variation in pressure of but 2 to 10 mm. of water, and the opening of a petcock under the spirometer had scarcely any effect on the position of the bell, so evenly balanced was the pressure.

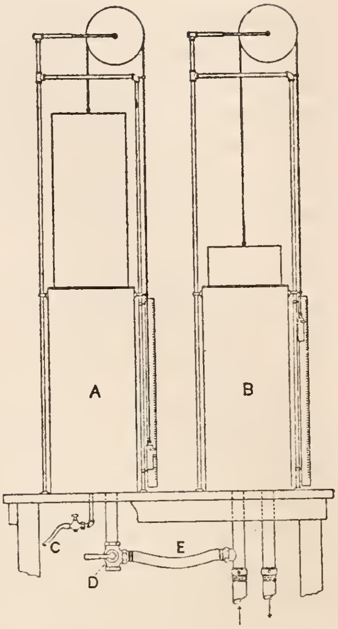

Fig. 2.—Double spirometer. *B*, main spirometer; *A*, duplicate spirometer used as reservoir; *C*, connection with oxygen-supply; *D*, three-way valve between *A* and *B*; *E*, rubber tubing connecting *A* and *B*.

Adjustment to subject.—To permit raising and lowering the connections with the subject on the treadmill, a 2-foot length of corrugated flexible metal tubing was introduced on one side and on the opposite side a rubber hose was inserted (*E*, fig. 1), 5 cm. in diameter, of about the same length as the metal tubing. This permitted the necessary up-and-down adjustment to the height of the subject and the pitch of the treadmill. For conducting the air from the spirometer to the absorber table, rubber tubing 28 mm. in diameter was used.

Meter.—An integrating meter,[1] capable of being read to 10 c. c., was used for measuring the oxygen consumption. As the experimental periods seldom exceeded 12 minutes and the room temperature was fairly uniform, temperature changes were for the most part insignificant, though always measured. The meter was equipped with an accurate thermometer, which was read at the beginning and end of each experiment. The average of these readings was used for the slight correction of the volume of oxygen due to temperature changes of the meter. The meter was calibrated[1] by passing weighed amounts of oxygen through it at various rates, and the factors thus obtained were used in all subsequent computations. Several calibrations were made during the course of the investigation with approximately uniform results, which were but the fraction of 1 per cent high. This meter proved very satisfactory, especially the integrating feature, which eliminated the danger, ever-present with other types of meters, of failure to record accurately the total number of revolutions of the pointer. The oxygen used in the experiments was made and supplied by the Linde Air Products Company.

---

[1] The meter used was made by the American Meter Company, New York, N. Y., their 0.1 cu. ft. wet test meter (No. 613), fitted with dial to read in liters. One revolution is equivalent to 3 liters, the total reading will run to 1,000 liters, and the volumes may be read to 10 c. c.

Barometer.—In the 12-minute periods of this research the barometric changes under ordinary atmospheric conditions were almost negligible. For measuring such changes a barograph was used, checked by a reliable barometer, and read to 0.1 mm. These readings were made at the beginning and end of each period, the average being used for reducing the data for the oxygen consumption to standard conditions.

Kymograph.—The usual Porter kymograph[2] was employed, but in place of records on smoked paper, pen-and-ink tracings on an unsmoked glazed paper were obtained. The pen, which was fastened to the counterpoise of the spirometer-bell, was a small glass capillary pen with platinum tip, such as is employed on many forms of automatic reading devices in large steam and electric plants.[3] This method was found to be simpler and cleaner than working with smoked paper and a varnishing solution. The speed of the kymograph-drum was 1 revolution in 15 minutes. A small pen, such as is used with the ordinary barograph, was attached to a signal magnet connected with the clock, and a record thus obtained in minutes on the glazed paper.

Respiration counter.—The number of respirations during the period was at first counted from the tracings of the pen attached to the spirometer-bell. Later a device (see fig. 3) was attached to the arm of the spirometer (see *A*, fig. 3). The cord *B*, leading to the counterpoise of the spirometer-bell, by rubbing on the fiber sleeve *C* caused the platinum points E and E_1 to dip into the mercury cups D and D_1 and complete a circuit to a counting device known in the telephone trade as a "p. b. x. message register." (See fig. 4.) This device proved a great labor-saver in counting the respiration tracings on the kymograph.

---

[1] Benedict, Phys. Review, 1906, **22**, p. 294.

[2] Harvard Apparatus Company, Dover, Massachusetts.

[3] The pen which gave the most satisfactory results was the Cochrane pen, supplied by the Harrison Safety Boiler Company of Philadelphia, Pennsylvania. It was about 40 mm. long and 6 mm. in diameter. With ordinary care the pen withstood a remarkable amount of use before it was worn out.

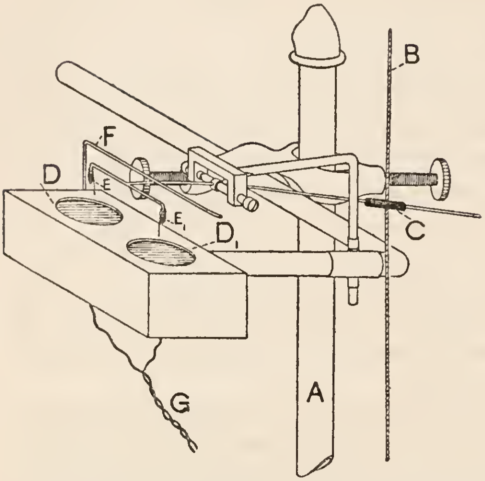

Fig. 3.—Respiration counter.

A, spirometer frame; *B*, cord from spirometer-bell leading to counterpoise; *C*, fiber sleeve; *D*, D_1, mercury cups; *E*, E_1, platinum-pointed fork for completing the circuit through *D* and D_1; *F*, stop; *G*, leads to electrically operated counter shown in fig. 4.

Ventilation recorder.—The total volume of air drawn into the lungs was registered by means of an attachment previously described,[1] and commonly referred to as the "ventilation adder." This consists of an aluminum wheel (*w*, fig. 1) attached to the apparatus in such a manner that each downward movement of the spirometer-bell due to inhalation by the subject moves the wheel upward. By means of a signal magnet, each revolution of the wheel is recorded upon the kymograph. From this graphic record and the volume corresponding to a revolution of the wheel, the total inspiratory ventilation can be calculated. At first the pulmonary ventilation during grade walking was found by actual measurement of the pen tracings on the kymograph, but later with the ventilation adder. The ventilation data secured have been reduced to standard conditions for temperature and pressure for recording in the tables.

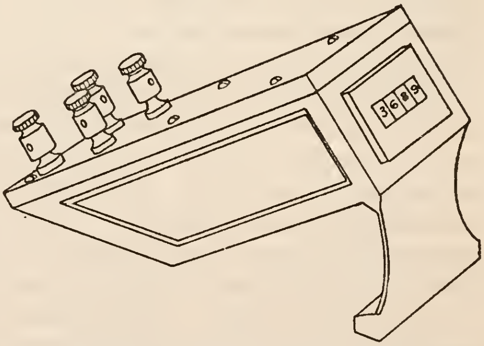

Fig. 4.—Electrical counter for recording number of respirations. For operating device and connections with the apparatus, see fig. 3.

Mouthpiece.—The mouthpiece used was of the Denayrouse type.[2] At the beginning of the study strips of surgeon's plaster across the lips were used with all the subjects to prevent possible leakage around the mouthpiece, but later these were omitted with W. K. and E. D. B. after they had become accustomed to the conditions. The normality of long-continued breathing through the mouthpiece, especially under the conditions of the grade-walking experiments, was tested in a series of experiments. The results of these tests are discussed on page 177.

---

[1] Benedict, Deutsch. Archiv f. klin. Med., 1912, **107**, p. 176; see also Carpenter, Carnegie Inst. Wash. Pub. No. 216, 1915, p. 40.

[2] P. Regnard, Recherches expérimentales sur les variations pathologiques des combustions respiratorires, Paris, 1879, p. 286; also Carpenter, Carnegie Inst. Wash. Pub. No. 216, 1915, p. 54.

The valve-operating device.—The method of operating the valve which connects the subject with the air-circuit is shown in figure 5, page 28. An arm on the stem of the valve is connected by a cord F to a bar K, which is supported on a button L. (See, also, fig. 1, p. 19.) When the operator pushes forward the lever J, L is forced from under the bar K and the tension of the spring M turns the valve. Resetting the button L and shifting the cord to the other side of the arm k (see fig. 1) permit the closing of the valve at the end of the period by the same method. This arrangement allows the operator to stand behind the subject, who thus has no knowledge as to when the period is to begin and end. The proper operation of the apparatus requires that the valve should be opened and closed at the end of a normal respiration, which is noted by the movement of a bit of goose-down affixed to the outlet of the valve. This material was not affected by the moisture of the breath, and, being light, instantly showed the point of change in the current of air at the end of an expiration.

By-pass.—As in other experiments made in this Laboratory on muscular work,[1] the ventilating air-current was carried to within a few centimeters of the mouthpiece by means of a supplementary pipe C (fig. 1), operated by a by-pass valve B. This by-pass valve was opened by a hand lever a few seconds after the beginning of an experimental period and closed a few seconds before the end of the period. This prevented any possible difficulty in obtaining sufficient ventilation for the subject and obviated an excessive dead space.

Rate of ventilation.—The rate of ventilation during all of the walking experiments was the maximum capacity of the blower, namely, 100 liters per minute, while for the standing experiments a rate of 65 liters per minute was generally maintained.

Tests of the Universal Respiration Apparatus.

Although the efficiency of the absorbing system of the universa respiration apparatus has been thoroughly and repeatedly demonstrated, it seemed advisable to test this point further before beginning the research, since in the walking experiments a ventilating air-current with a rate as high as 100 liters per minute was to be used in place of the current of 30 to 40 liters per minute employed in most of the researches with this apparatus. If the water-absorbers were inefficient, moisture would be carried over to the carbon-dioxide absorbers and there collected; under these circumstances the change in weight of these absorbers would not represent the amount of carbon dioxide expired by the subject, but would give higher values. If, on the other hand, the air-drier in the soda-lime train (i. e., the Williams bottle following the two carbon-dioxide absorbers) were inefficient, so that moisture carried over from the moist soda-lime was not wholly absorbed by the sulphuric acid in the Williams bottle, the total increase in weight would be less than the actual amount of carbon dioxide expired by the subject.

---

[1] Benedict and Murschhauser, Carnegie Inst. Wash. Pub. No. 231, 1915, p. 33.

Efficiency of the water-absorbers.—During rest experiments the usual rate at which the absorbing system is run is not far from 30 to 35 liters per minute. For testing the efficiency of the water-absorbers for the special demands of this research, the absorbing system was run at 65 to 100 liters per minute without a subject. The gain in weight of the water-absorbers and the loss in weight of the moistener were then compared. If the water-absorbers were efficient, their gain in weight would be equal to the loss in weight of the moistener. One such test showed a difference after 1 hour of 0.19 gram. If, in 12 minutes (the usual length of a period), such an amount of unabsorbed water were carried to the soda-lime containers and there absorbed, the error in the determination of the carbon dioxide expired would amount to 1.5 c. c. per minute. In another series of experiments with five periods, the first Williams bottle gained 116 grams, while the second gained only 2 grams. In still another test an additional Williams bottle was used. The first gained in weight 165.55 grams, the second 4.70 grams, while the third lost 0.1 gram in a period of 3 hours. As it was the practice to remove the first Williams bottle each day and advance the second Williams bottle to first place, while a freshly filled bottle was used for the second water-absorber, it may be safely assumed that none of the moisture in the ventilating air-current reached the carbon-dioxide absorbers. In the usual rest experiments, in which the ventilation is about 30 liters per minute, the "error" would be negligible in all cases.

Efficiency of the air-drier.—The second point, viz, that the carbon-dioxide absorbers lost no moisture that was not recovered by the air-drier, was tested by passing the ventilating air-current through the soda-lime containers, which were weighed separately. The moisture taken up by the air in passing through the moist soda-lime should then be entirely removed in the following Williams bottle or air-drier. The largest gain found during any test was equivalent to an error of 3 c. c. per minute in the carbon-dioxide determination, while the average error in a series of tests was but a fraction of 1 c. c. per minute. It was considered, therefore, that the absorbers as used in this research were efficient, *even at the high rate of ventilation of 100 liters per minute.* During the standing experiments the rate of ventilation was 65 liters per minute, which allowed still greater efficiency in the absorbers.

Tests for tightness.—The care used in making all of the various joints in the system air-tight was well worth the effort, for the apparatus was surprisingly free from leaks. At the beginning of each day's experimenting a preliminary test for tightness was always made, and if the pointer on the kymograph-drum showed any variations within 3 minutes, a leak was sought for. During the research further tests of 15 and 20 minutes were likewise made for possible leaks. Early in the experiment these longer tests were made daily, but later they were made but once a week or even once in two weeks.

Tests of air in the system.—Before beginning the experiment of the day it was the practice to empty the bell of the spirometer and introduce 4 or 5 liters of oxygen into the system. The ventilating apparatus was then operated for a few minutes, the spirometer again emptied, and refilled with oxygen. This prevented any danger of deficiency in the oxygen-content of the air and an accumulation of nitrogen. Duplicate analyses of the air after the completion of a series of seven successive experimental periods with W. K. on one day gave results for oxygen of 21.90 and 21.93 per cent.

TREADMILL.

A detailed description of the treadmill was given in the report of the previous study in which this apparatus was used.[1] It consists of an endless leather belt which travels over two broad wooden pulleys, supported on ball bearings, at the ends of a wooden frame. The mill is actuated by a ½ h. p. electric motor. The belt between the pulleys is supported by a considerable number of steel tubes, set close together but without touching in a steel framework. Each tube is fitted at its two ends with annular steel ball bearings. A rolling, frictionless surface is thus provided for the man to walk upon, which is both substantial and smooth. The speed of the motor may be varied at will. Some slight alterations were made in the treadmill for this research, but it was essentially as used in the previous study with the subject walking. The general arrangement of the apparatus is shown in the frontispiece and in figure 1, page 19.

Distance counters.—The use of the two counters recording the number of revolutions of the front pulley of the treadmill was continued in this research, except that the "continuous counter," for recording the total number of revolutions, was moved to the rear of the treadmill frame and operated by a wire from the front pulley. This change was made so that the counter might be in view of the operator standing at the absorber table. The other counter, which is shown in figure 5, and records the number of revolutions of the pulley during the experimental period, is known as the "period counter." It is fastened to the front pulley of the treadmill and is operated by the bar *J*, which turns the valve connecting the subject with the ventilating circuit. When *J* is thrown at the beginning of the period, it forces the arm *A* from its position at stop *B* over to stop *C*. This changes the position of the bar *D* from *d* to d_1. In the latter position the button *E* strikes against *D* with each revolution of the pulley, this contact operating the counter *R*. A measurement of the outside circumference of the belt (4.355 meters) and a series of tests showed that one revolution of the pulley was equivalent to 1.328 meters. Hence, from the total number of revolutions of the pulley as recorded by the counter during the period and the equivalent of one revolution of the pulley (1.33 meters), the exact distance walked by the subject during the period could be calculated. By readings of the "continuous counter" at the times when the valve is opened and closed, it is possible to verify the records of the "period counter," so that a check on the record of the distance walked was obtained.

---

[1] Benedict and Murschhauser, Carnegie Inst. Wash. Pub. No. 231, 1915, p. 34.

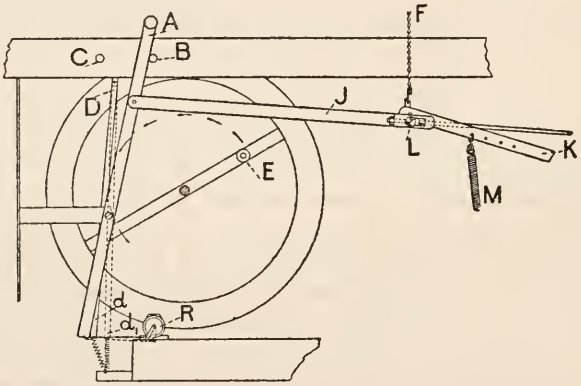

Fig. 5.—Detail of valve-operating device and period counter.

Valve-operating device.—*J*, bar which, when pushed forward, forces button *L* from under bar *K*. The tension of spring *M* then acts through cord *F*, operating arm *k* and valve *D* in figure 1 (p. 19), connecting subject with the ventilating circuit. (See *I*, *k*, *D*, *J*, *L*, *K*, and *M*, fig. 1, p. 19.)

Period counter.—When the bar *A* is against the stop *B*, the pivoted brass bar *D* is in position *d*. The brass button *E* then slides past the bar *D* without displacing it. When the valve-operating device *J* is thrown forward, the bar *A* is pushed against the stop *C* and the bar *D* comes into the position d_1. The button *E* then strikes the bar *D* on each revolution of the pulley and the displacement of *D* operates the counter *R*, giving a record of the number of revolutions of the front pulley during the experimental period. (See also fig. 1, p. 19.)

Control of the speed of walking.—By means of a stop-watch the time necessary for 10 revolutions of the front pulley as shown by the counter was determined, and then, by reference to a previously prepared table, the speed of the treadmill could be readily obtained. The speed was controlled largely by means of the starting-box, which permitted moderate adjustment. As the experiments progressed, however, there was frequently a change in the speed of the treadmill. This change was gradual and could not be easily detected. It often happened, therefore, that when the speed was properly adjusted at the beginning of the experiment it would be found that as time passed the rates of walking for the different periods varied slightly from each other. During the walking experiments in which high grades were employed, use was made of the brake Q, Q_1, bearing on a pulley fixed to the motor shaft, to aid in securing satisfactory speed adjustments. (See fig. 1.)

Angle of ascent.—By means of two nuts sunk in the head of the treadmill frame and two long screws (see N, and N_1, fig. 1, p. 19), it is possible to elevate the front end of the treadmill to an angle of slightly over 45°. A spirit-level (O in fig. 1), fastened to the front of the treadmill, indicates when both sides have been adjusted equally, so that the belt will run smoothly and true. To determine the elevation of the treadmill, a light wooden triangular frame was constructed, which is shown in figure 6. This was pivoted at A and E and could be adjusted at B, by means of a slot and set-nut. The distance between A and C was exactly 100 cm. When used to find the angle of elevation, this frame was placed upon the walking surface of the treadmill, with the edge AE resting on the leather belt. It was then adjusted at B until the surface AB was perfectly level, as shown by the spirit-level S. The elevation DC was next measured and used to find the sine of the angle, or the "slant-height." Since AC is 100 cm., the slant-height may be readily expressed as per cent. Accordingly, when the grade is given as 10 per cent, it is meant that the subject in walking a linear distance of 100 meters raised himself to a height equivalent to 10 meters. It should be borne in mind that for the 100 linear meters thus walked, the energy expended over and above the standing requirements was made up of the energy required (1) for the elevation of the body and (2) for transporting the body over the horizontal component. This horizontal component was found from the cosine of the angle. Thus, the subject, in walking on a 10 per cent grade at a rate of 100 meters per minute, walked a linear distance of 100 meters and the vertical component would be 10 meters, while the horizontal component would be 100 × cosine 5° 44′ 30″, or 99.5 meters.

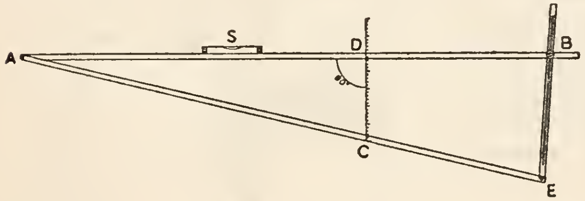

FIG. 6.—Framework used in determining the angle of ascent.

MEASUREMENT OF THE STEP-LIFT.

With each step in walking, the body is raised to a greater or less degree in a vertical direction, and this becomes an appreciable factor in the amount of work which is done. In the previous research in this Laboratory on the muscular work of walking, a dual record of these movements was obtained by means of a work-adder wheel, the spring pointer introduced by Professor Carl Tigerstedt,[1] and a kymograph record. The same method of measurement was used in this research (see fig. 7), except that the cord leading to the work-adder wheel was not attached directly to the subject. Instead, a light wooden fork was employed, which was 2 meters long and pivoted at one end, while the prongs were held closely at the subject's shoulders by elastic webbing. (See *S*, fig. 1, p. 19.) The cord *T* (figs. 1 and 7) from the work-adder wheel was fastened to this fork at a point directly behind the subject's neck. Although this attachment was not so near the center of gravity of the body as it might be, the results obtained with it were very positive and showed such slight movements as shifting the weight of the body from one foot to the other—a movement scarcely noticeable to the observer—while it was less affected by the relative position of the subject on the treadmill. The work-adder wheel was directly con-

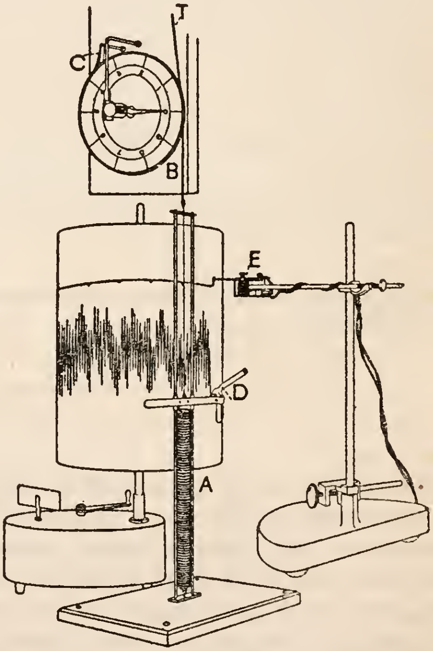

FIG. 7.—Step-lift recorder.

T, cord fastened to fork at back of subject (see fig. 1, p. 19); *A*, spring providing tension on cord *T*; *B*, recording wheel revolved by the friction of cord *T*; *C*, laminated spring-steel pawl to prevent back-lash; *D*, pen for tracing record; *E*, signal magnet and pointer for recording time.

---

[1] C. Tigerstedt, Skand. Archiv f. Physiol., 1913, 30, p. 299. See special application of this pointer under the conditions of this research in Benedict and Murschhauser, Carnegie Inst. Wash. Pub. No. 231, 1915, p. 39.

nected to the shaft of a revolution-counter, and a record of the total movement of the wheel was thus obtained. The total distance the body was raised would theoretically be that found by multiplying the number of revolutions of the wheel by its circumference. These readings were made for 10 minutes during every period 12 or 13 minutes in length.

Another change in the procedure was the use of ink in place of smoked-paper tracings on the kymograph drum. The speed of the kymograph was regulated to one complete revolution in 3 minutes. If a lower speed than this was used, the tracings of the pen were frequently superimposed upon one another, making it difficult to distinguish the individual steps. As it was necessary to readjust the kymograph between the end of each revolution and the beginning of the next one, only three 3-minute tracings could be obtained during the period. The average of these three 3-minute records was taken as the average elevation of the body per minute during the entire period of 12 or 13 minutes. The tracings upon the kymograph-drum were used, however, simply to check the records of the step-lift counter in case it failed to act properly.

A criticism[1] has recently appeared of the method used by Benedict and Murschhauser[2] in measuring the step-lift, to the effect that, in walking, their subject changed his position on the treadmill, thus changing the length of the cord from his back to the pulley from which the cord ran to the kymograph. Since the criticism would apply to some extent to the method used in this research for measuring the step-lift, several experiments to test this point were made on a subject not used in the research of Benedict and Murschhauser, as neither of these was available.

A small incandescent lamp was inclosed in a tin can with a hole in it through which the light would shine. One of these lamps was fastened to the back of a subject at the point of attachment used by Benedict and Murschhauser (the waist-line) and a second light to the point between the shoulders used in the present research. For a scale of measurement, two lights, 1 meter apart, were affixed to a board centered in the same plane and behind the subject. Photographs were then taken of the movements of the spots of light at the waist and shoulders, respectively, during the cycle of one double step when the subject was walking on a level and on grades of approximately 10 and 25 per cent, with a speed in each case of 71 to 74 meters per minute. These photographic records were made not only with the camera stationary, but also with the camera rotated, so that tracings were obtained across the full length of the photographic plate.

By measuring the spacing of the light spots on the photographic plate, and the distance on the 1-meter scale, it was found that in walking on a level there was an average total forward-and-back movement at the waist of 1.98 cm., and at the shoulder of 0.79 cm., corresponding to a displacement from the vertical of 0.99 and 0.40 cm., respectively, while for the 10 and 25 per cent grades the displacement was even less. For a radius of 1.5 meters, which represents the length of the cord from the shoulders to the pulley, and which connects the subject with the step-lift counter, this displacement would amount to a rise above the horizontal of 0.01 cm., an amount too small to be considered.

---

[1] Liljestrand and Stenström, Skand. Arch. f. Physiol., 1920, **39**, p. 167.

[2] Benedict and Murschhauser, Carnegie Inst. Wash. Pub. No. 231, 1915, p. 39.

A comparison was also made at this time between the respective readings of the perpendicular lift, as shown by the light spot at the waist (Benedict and Murschhauser method), and that at the shoulder (H. M. S. method), and of the kymograph tracings taken simultaneously. On one series of plates it was found that, for horizontal walking, the movement of the light spot at the waist was larger than that at the shoulder by 1 per cent, while the movement of the shoulder light spot was greater than that recorded by the kymograph by 1.5 per cent. On another series of plates it was found that the shoulder movement was slightly larger than the waist movement. In either case it may be assumed that the variations agree within 1 or 2 per cent of each other. In the case of the grade walking the differences were of the same order.

Measurements were likewise made with the subject walking up the inclined treadmill when it was stationary and again when it was running. The subject with the light at the waist stepped from a stool on to the treadmill and walked to the top, thus giving an opportunity for the measurement of the step-lift superimposed on the grade-lift. The mill was at an incline of 18.4 per cent. By measuring the light spots recorded on the plate when the subject walked up the stationary mill, it was computed that the grade was 14.7 per cent, i. e., the light spots did not correctly show the grade by −3.7 per cent. From the plates made when the subject walked up the mill while it was running, the grade, computed from the light spots, was 19.9 per cent, or 1.5 per cent too high. Evidently the measurements of the step-lift can only be regarded as approximate.

The average step-lift, measured under these conditions, was 5.23 and 6.48 cm. per step, respectively, with the mill stationary and running. Assuming 110 steps a minute, there was a lift of approximately 7 meters per minute when the mill was running. From table 55 (see p. 214), we find that E. D. B. on December 15, walking on a 15 per cent grade and with a speed of 75 meters per minute, had an average step-lift of 4.89 meters per minute, as measured by the kymograph; and on January 1, with a 20 per cent grade and a speed of 80 meters per minute, it was 5.57 meters per minute. If these figures are increased by 1.5 per cent to correspond with the measurements from the photographic records, which were that much higher than the kymograph records (p. 32), his step-lift per minute would have been 5.0 and 5.7 meters as compared with 7 meters per minute for the subject of this test.

Considering the difference in the grades and speeds, as well as the difference in subjects, and the considerable lapse of time between the results obtained in the research and in these later tests, there is more approximation here than might have been expected.

Step-lift technique during grade walking.—The use of the fork on the shoulders, as indicated in figure 1, during experiments on horizontal walking, is, we believe, without serious criticism. After our series of experiments had been completed, the results computed and tabulated, and an analysis of the data was being made, a criticism arose to the effect that the device pictured in figure 1 would not record the true step-lift, but might include in its registration a not inconsiderable part of the grade-lift. It appeared that the most logical procedure would be to place the fork parallel with the belt of the mill and to run the cord from the fork to the first pulley in a line at right angles to the belt of the mill, continue it over the second pulley, and then down to the pointer. It was argued that by this method no movement in the direction that the belt was traveling could be registered, except that of a very long pendulum, which, at this arc, namely, 110 cm. or more, would be negligible. Consequently, during the preparation of this manuscript for publication, a series of experiments was made to test the effect of this change n procedure. Since the results relate more particularly to the study of the step-lift during grade walking, their discussion is deferred until the results of the grade-walking experiments are considered. (See p. 243.)

METHOD OF STEP-COUNTING.

For securing a record of the number of steps taken by the subject, a counter attached to the rear end of the treadmill was connected with the ankle of the subject by means of a long, weak, spiral spring. (See *X*, fig. 1.) This spring had sufficient tension to operate the counter when the leg was thrown forward, but at the same time put no restriction upon the movements of the subject as he walked. As it was not possible to obtain the reading at the exact beginning of the period, it was the practice to read the step-counter at the end of the first minute of the period and again at the end of the eleventh. The difference in the records, when multiplied by 2, gave the total number of steps taken during the 10 minutes of a period 12 or 13 minutes in length.

APPARATUS FOR DETERMINING THE PULSE-RATE.

Benedict and Murschhauser,[1] in their report on the energy transformations in horizontal walking, recorded a few pulse-rates with the subject walking which were taken by the writer with a string galvanometer. These were made largely to test the possibilities of this method for determining the pulse-rate during muscular work. While conditions did not permit at that time the collection of any considerable amount of data, the method was shown to be practicable. The results here reported were first obtained by means of a Bock-Thoma oscillograph and later by the use of a Cambridge string galvanometer, somewhat modified, especially as to the registering apparatus.

---

[1] Benedict and Murschhauser, Carnegie Inst. Wash. Pub. No. 231, 1915, pp. 54 and 55.

OSCILLOGRAPH.

The Bock-Thoma oscillograph[1] was equipped with four filaments, but only one was used. This was of platinum with a diameter of 0.0025 mm. and a resistance of 5,000 ohms. In place of the regular time equipment, a Jaquet graphic chronometer was employed, the pointer of which interrupted a beam of light in front of the camera-slit. As only the pulse-rate was desired in these experiments, the speed with which the photographic paper was supplied to the camera was reduced to approximately 25 cm. per minute. At this speed each pulse-beat could be easily counted on the record and the distance between the second marks could be readily estimated to tenths.

It was found difficult at that time to obtain photographic paper of American manufacture that was sufficiently sensitive for use with this instrument, while the paper originally supplied with the instrument was expensive and did not keep well. Ultimately a satisfactory European paper was obtained. The greatest difficulty, however, was found with the filaments of the oscillograph. These were exceedingly delicate and liable to damage. Finally, when war conditions made it impossible to replace broken filaments, the use of the oscillograph was discontinued. A typical record of the pulse-rate as obtained with this instrument is given in *C*, figure 8.

CAMBRIDGE STRING GALVANOMETER.

In the fall of 1916 a Cambridge string galvanometer, which had previously been used in the psychological work of the Laboratory, was employed for measuring the pulse-rate of the subjects in the walking experiments. For this purpose a camera of the so-called Morse type[2] was substituted for the camera provided with the Cambridge instrument. This apparatus was so changed that the mechanism supplying the photographic paper to the camera was driven by a 1/80 h. p. motor of 2,200 r. p. m., equipped with a rubber friction drive in place of the usual worm and gear, also with a suitable set of reducing pulleys. The speed with which the paper was being fed to the camera was indicated by a pointer fixed to the feed-shaft revolving over a graduated dial. By means of a hand rheostat, the speed of the

---

[1] Groedel, Theo. and Franz, Deutsch. Archiv f. klin. Med., 1912, **109**, p. 52.

[2] Manufactured by Edelmann and Sohn, Munich, Germany.

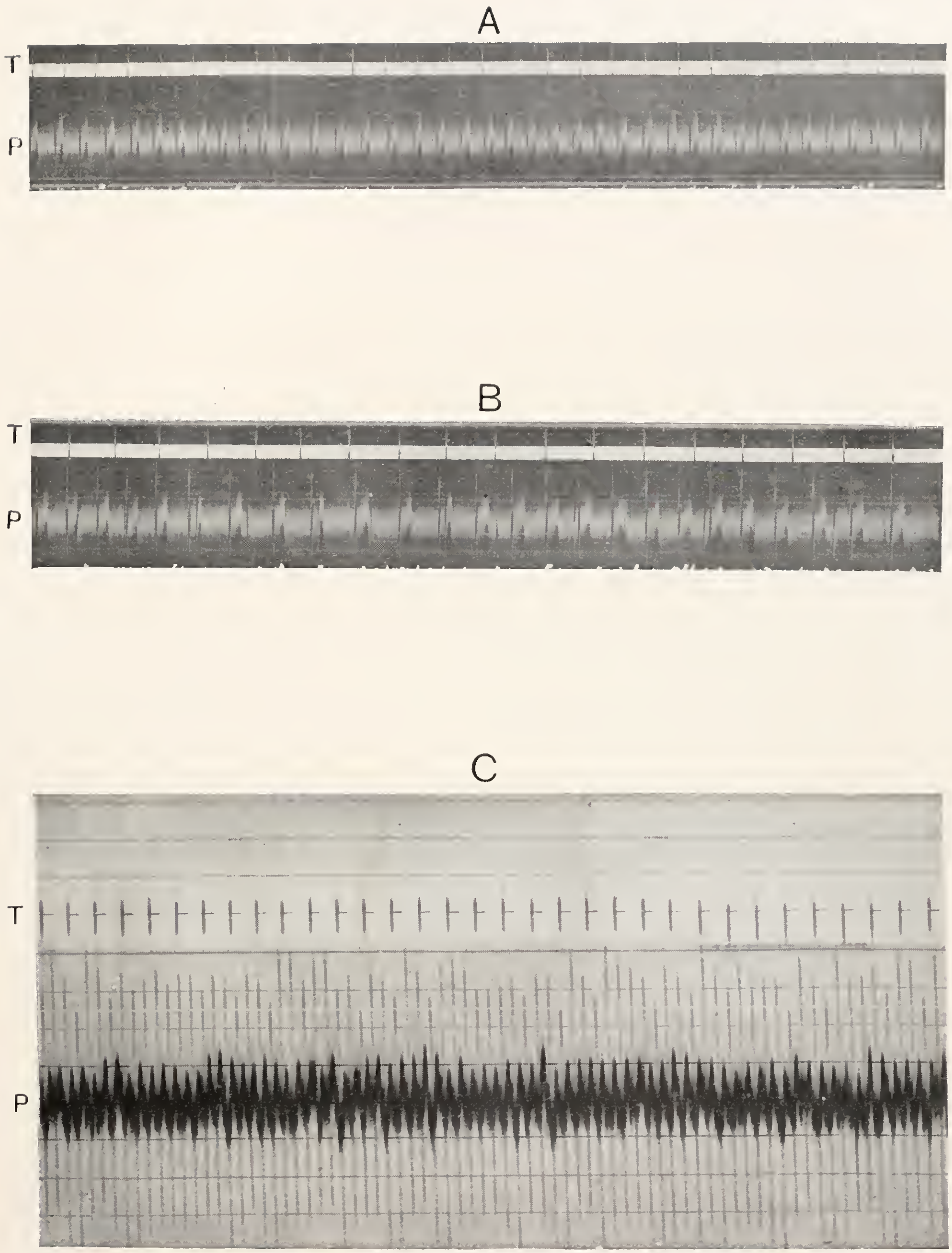

Fig. 8.—Typical records of pulse-rate as obtained with oscillograph and string galvanometer. *A* and *B*, records with string galvanometer: *C*, record with oscillograph. *T*, time; *P*, pulse-rate.

paper could be varied from 25 to 100 cm. per minute. As with the oscillograph, the rate of speed in supplying the paper to the camera was kept as low as was consistent with clear registration, and the time was recorded by means of a Jaquet chronometer. Typical records of the pulse-rate as obtained with the Cambridge string galvanometer, with the modifications noted, are given in *A* and *B* in figure 8.

ELECTRODES.

In the beginning of the research the subject was connected with the galvanometer by means of zinc rods, wrapped in flannel and moistened with zinc-chloride solution. These he carried in his hands. The difference in pressure with which the subject at times gripped the electrodes caused a varying resistance in the system and led to more or less difficulty. Various other forms of electrodes were tried, but those which were most satisfactory and which were used in practically the whole study consisted of brass disks about 2 cm. in diameter, embedded in kaolin mixed to a paste with dilute zinc-sulphate solution. This paste was plastered on the chest just above and below the nipples and the whole mass covered with a small section of a rubber tennis-ball held in place by strips of surgeon's plaster. The rubber covering tended to prevent the drying out of the moisture in the paste, which would change the conductivity of the system. Over each rubber cover was placed a pad of absorbent cotton and one or two large elastic bandages to provide a uniform pressure upon the electrodes.

The leather belt over the pulleys of the treadmill developed considerable static electricity. Furthermore, leakage from the 220-volt system used in driving the treadmill caused considerable difficulty and was a constant source of danger to the delicate string of the galvanometer. At first, use was made of the method employed by Benedict and Murschhauser[1] of grounding the treadmill by means of small sections of brass chain trailing over the surface of the leather belt, the chains being connected to a rod and attached to a water-pipe in the laboratory. Later the use of the brass chain was discontinued and it was replaced by a roll of fine brass gauze which bore upon the full width of the leather belt. (See *W* and W_1, fig. 1, p. 19.) Under these conditions it was possible to obtain a record of the pulse-rate with the subject walking and wearing rubber-soled shoes. As at times difficulties would develop unexpectedly, this method was also abandoned, and instead of grounding the treadmill, it was arranged to ground the subject. This was done by a third electrode similar to those already described, which was placed upon the abdominal wall and connected to a water-pipe in the laboratory. (See *V*, fig. 1, p. 19.) The new method gave excellent results and enabled the subject to walk on the treadmill with ordinary shoes without disturbing the delicate string of the galvanometer.

---

[1] Benedict and Murschhauser, Carnegie Inst. Wash. Pub. No. 231, 1915, p. 37.

Technique for Securing Records of the Pulse-Rate.

The electrodes in the moist kaolin paste were put in position as previously described, one above the right nipple and the other somewhat lower down on the left side, and fastened in place by means of adhesive tape and elastic bandages. The grounding electrode was fastened to the body near the umbilicus in a similar manner. The leads were then tested for response and for any fault in the grounding of the subject. At the beginning of the period, a signal was given to the operator in the galvanometer room and within a minute of the beginning of the experimental period a photographic pulse-record for approximately 60 seconds was made. In the course of 3 or 5 minutes another record was taken, and a third at about the end of the tenth minute. Thus, during a 12-minute period, three records were obtained at approximately regular intervals. To obtain the pulse-rate per minute, the time and pulse-rate were subsequently counted by two assistants independently from these records and the average of the three records was taken as representative of the pulse-rate during the period. If, in any instance, difficulty was experienced in counting the records, or if the two assistants failed to agree in their counts, another count was made by a third individual. In some cases, owing to technical difficulties, it was possible to use only a portion of the record for the final count.

DETERMINATION OF THE BODY-TEMPERATURE.

Records of the body-temperature were secured in the rectum by means of an electrical resistance thermometer. The resistance coil embedded in Woods metal[1] in a pure-silver tube was provided with leads 10 meters long connecting the thermometer with a d'Arsonval galvanometer and Wheatstone bridge placed in one corner of the room. Two of these rectal thermometers, each having a resistance of about 12 ohms, were used during the study. The apparatus was calibrated at temperatures of from 35° to 39° C. at intervals of 0.25° to 0.5° by immersing the thermometer bulb in a Dewar flask. These temperatures were read from a standard Richter mercurial thermometer, with an accuracy of 0.01° C. From the points thus obtained, curves were constructed from which temperatures to 0.01° C. were secured. These curves were checked at frequent intervals during the course of the study, to make sure that no change had taken place in the value of the resistance thermometers.

Before the experiment of the day began, the thermometer was inserted in the rectum of the subject to a definite depth, with the aid of a slight coating of mucochondrin. The leads were fastened to the buttocks by means of a small piece of adhesive tape to prevent any displacement of the thermometer as the subject walked. They were then passed between the legs and out through the fly of the walking suit worn by the subject. The pointer on the dial of the Wheatstone bridge was placed upon the 100 division-mark of the slide-wire and a balance obtained with the compensating leads by an adjustable resistance inserted between the galvanometer and the bridge. The compensating leads were then replaced by the leads in the circuit of the thermometer. At first the temperature records were secured at the beginning and end of the periods, but after a few days they were taken oftener, usually every 2 minutes, and sometimes every minute. Readings were also made in the intervals between the periods.

---

[1] Riche and Soderstrom, Arch. Intern. Med., 1915, **15**, p. 820.

Balances with the compensating leads were made at intervals during the forenoon. Between the periods, especially when the subject had been walking, he was allowed to sit on a stool placed on the treadmill or to stand erect. In either case it became necessary for his comfort to throw a blanket around him. It was found that if the blanket inclosed a portion of the leads (ordinary lamp cord), the balancing became extremely difficult; consequently, care was exercised to prevent more than 12 to 18 inches of the leads from being inclosed within the folds of the blanket. It was also observed at times that sitting affected the temperature reading, this being due, possibly, to a change in position of the thermometer within the walls of the rectum. These conditions were hard to avoid, but at all times the greatest care possible was used in inserting the thermometer to a uniform depth and in balancing with the compensating leads at frequent intervals.

On a few days, when W. K. was doing a large amount of work, the weather was warm and an electric fan was allowed to blow a current of air across his face and shoulders. Except in these few experiments, the subjects walked in the still air of the room, wearing heavier or lighter clothing in proportion to the amount of work which they were expected to perform. The effect of a moving air-current on the metabolism, general comfort, and efficiency of an individual has been emphasized by Hill in a recent report.[1] With the few exceptions stated above, we made no attempt to control the body-temperature of the subject, other than by keeping the room-temperature at approximately 20° C. and allowing the use of a blanket after the cessation of the exercise of walking.

DETERMINATION OF THE BLOOD-PRESSURE.

During the last month of the study, that is, subsequent to March 19, 1916, some determinations were made of the blood-pressure of E. D. B. as a part of the walking experiments. Attempts to record the blood-pressure while the subject was walking were unsuccessful, on account of the movements of the body. It was necessary, therefore, to make the measurements immediately after the walking had ceased. The apparatus used consisted of an Erlanger sphygmomanometer, with which a permanent record was secured on the kymograph. Only the systolic pressure, however, was noted. To assist in determining this point, we also employed a Nicholson sphygmomanometer, placing a cuff on the forearm and noting the first indication of the pulse from the movement of the Feddé pith-ball.[1] The pressure was then read on the Erlanger sphygmomanometer. This double method of securing the systolic pressure was found to be more satisfactory under these special conditions than the use of a stethoscope on the brachial artery or placing entire reliance upon the tracing of the pointer on the Erlanger sphygmomanometer.

---

[1] Hill, The science of ventilation and open air treatment, part I, Special Report, Ser. No. 32, Medical Research Committee, London, 1919.

The cuffs were placed on the subject's right arm before the experiment began and were worn by him during the entire forenoon. In the standing experiments, three determinations were made as near to the second, sixth, and tenth minutes of each period as possible. In the walking experiments, the pressure was applied towards the end of the usual preliminary walk. When all was in readiness, the treadmill was stopped and two determinations of the systolic pressure were made as quickly as possible. The walking then began again immediately and the period commenced with but little loss of time, usually not more than 1 or 2 minutes. At the close of the period, while the subject was still walking, the pressure was again applied, and as soon as the treadmill stopped a second series of records was secured. The average of these two observations, namely, the records after 10 minutes of preliminary walking, and after 10 or 12 minutes of walking in the period proper, are recorded as the blood-pressure for the walking period. It should be clearly understood, however, that these values were made while the subject was standing and 10 to 20 seconds after he had stopped walking.

ROUTINE OF EXPERIMENTS.

The approximate routine of an experimental period during a walking experiment was as follows: On the arrival of the subject at the Laboratory, records were made of the last meal taken and the hour it was eaten to insure that the subject was in a post-absorptive condition. The electrodes for the pulse-record were then adjusted, and if the exercise was to be severe, a change was generally made to a walking-suit. The man was then weighed with clothing, after which the rectal thermometer was inserted. When the subject mounted the treadmill, a safety belt attached to the ceiling was buckled loosely about his waist. The counters for recording the number of steps and the step-lift were connected and read, also both of the revolution counters on the treadmill. The subject then began the preliminary walking period. During this period a certain amount of air was withdrawn from the ventilating system and replaced by fresh oxygen, the absorbing bottles were weighed, and the system was tested for tightness. Approximately 2 minutes before the beginning of the walking period proper, the mouthpiece and nose-clip were adjusted. A signal was sent to the operator in the room where the pulse-rate was measured, and in quick succession readings were made of the ventilation adder, the oxygen meter and its temperature, the barometer, and the respiration counter, these readings being verified by a second observer. The kymograph on which the respiration was recorded was also started and the pens were adjusted.

---

[1] Wiggers, Circulation in health and disease, Philadelphia and New York, 1915, fig. 53, p. 198.

The walking period proper began when the subject was connected with the ventilating current of air by the opening of the valve at the end of a normal expiration and coincident with the starting of a stopwatch and the reading of the "continuous counter." Within the next 30 seconds, the by-pass *B* (fig. 1, p. 19) was turned, the kymograph was started, which gave a record of the height of the steps, and the step-counter and height-counter were read at 1 minute and 1 minute and 10 seconds, respectively. During the period that followed, the operators were occupied in admitting oxygen, recording the body-temperature and pulse-rate, resetting the valve-operating device in readiness for the end of the experiment, adjusting or replacing the kymograph-drum of the step-lift record every 3 minutes, and weighing and testing the carbon-dioxide absorbers for the next period. At about 9 minutes after the period began, the efficiency of the carbon-dioxide absorbers was tested by deflecting a portion of the air-current through a solution of barium hydroxide. At the eleventh minute of the period the step-counter was read; at 11 minutes and 10 seconds, the step-lift counter was likewise read and a warning signal sent to the operator in the pulse-record room. At approximately the twelfth minute, the valve was turned at the end of a normal expiration, a simultaneous reading of the "continuous counter" was made, and the period ended. Readings of the various counters were recorded, and when the carbon dioxide in the system had been completely absorbed, oxygen was admitted to bring the spirometer-bell to its original level. Finally, records were made of the oxygen-meter and its temperature and of the barometer.

Other periods followed with similar routine; between the periods the subject either sat, stood, or continued walking. During the interval between the periods, if the subject sat or stood, it was usually considered advisable to throw a blanket over his shoulders and around the body, as previously described, for ordinarily he was warm and perspiring freely after the muscular exercise of walking. Measurements were, as a rule, made in four to six periods during the forenoon. At the end of the morning the subject was released from the treadmill and weighed a second time. A typical record-sheet for one period of a walking experiment, with the necessary corrections and calculations, is given in table 2.

TABLE 2.—*Typical record of walking experiment.*

Subject, E.D.B. Date, February 2, 1916. Grade, 25 p. ct.

Last meal, 7 p.m.: Lamb broth, roast beef, mashed potatoes, squash, three slices bread and butter, apple pie.

Body-weight, with clothing:		
	9:15 a.m.	61.53 kg.
	1:00 p.m.	61.00 kg.
	Average	61.27 kg.

Period I.

Began walking, 10:00:00 a.m.
Period began, 10:13:20 a.m.

Air-current used = 100 liters per minute.
Duration of period, 12 min. 22-3/5 sec. or 12.387 min.

Carbon dioxide.

Absorbers BB + V	End	1913.59 gms.
	Start	1884.19 gms.
	Difference	29.40 gms.
Absorber 900		4.28 gms.
Total CO_2		33.68 gms.

Absorber 900	End	2574.42 gms.
	Start	2570.14 gms.
	Difference	4.28 gms.

Log. 0.5091 = 9.70680 - 10
Log. total CO_2 = 1.52737
Log. volume CO_2 = 1.23417 = 17.15 liters.

Oxygen.

	Meter.	Temperature.	Barometer	Barometer temp.	Valve correction.
End	854.60 liters	18.0° C.	772.1 mm.	21.4° C.	Start +2 mm.
Start	834.12 liters	17.8° C.	772.6 mm.	21.1° C.	End -0 mm.
Difference	20.48 liters	Av. 17.9° C.	772.4 mm.	21.3° C.	Diff. +2 mm.
Valve correction	0.09 liter				= +0.09 liter.
Corrected meter	20.57 liters				

Barometer	772.4 mm.
Correction for temperature	2.7 mm.
	769.7 mm.
Correction for aqueous vapor at 17.9° C.	15.2 mm.
Corrected barometer	754.5 mm.

Log. meter factor	0.00294
Log. reduction to 0° C. $\left(\frac{273}{290.9}\right)$	9.97237 - 10
Log. reduction to 760 mm. $\left(\frac{754.5}{760}\right)$	9.99685 - 10
Log. corrected meter (20.57 liters)	1.31323
Log. volume O_2	1.28539 = 19.29 liters

Respiratory quotient.

Log. volume CO_2	1.23417
Log. volume O_2	1.28539
Log. respiratory quotient	9.94878 - 10 = 0.89

Carbon dioxide per minute.

Log. volume CO_2 in c.c.	4.23417
Log. time (12.387 min.)	1.09272
Log. CO_2 per min. in c.c.	3.14145
CO_2 per min.	1385 c.c.

Oxygen per minute.

Log. volume O_2 in c.c.	4.28539
Log. time (12.387 min.)	1.09272
Log. O_2 per min. in c.c.	3.19267
O_2 per min.	1558 c.c.

Ventilation.

Ventilation adder wheel.

Start	0.00
End	83.75
No. of revolutions	83.75 x 4.9 liters = 410.38 liters.

$\frac{410.38}{12.387 \text{ min.}}$ = 33.13 liters per min. or 30.75 liters per min. (reduced).

Respiration rate.

Counter.

End	3249
Start	2974
Difference	275

$\frac{275}{12.387 \text{ min.}}$ = 22.1 per min.

TABLE 2.—*Typical record of walking experiment* (continued).

Distance walked.

	Continuous counter. Preliminary.	Continuous counter. Period.	Period counter.
End	21216	21638	57037
Start	20765	21216	56614
Revolutions of wheel	451	422	423
Average revolutions per min.		422.5	

Total distance preliminary to period.
451 x 1.33 = 602 meters.

Distance per minute in period.
$\frac{422.5 \text{ x } 1.33}{12.387 \text{ min.}}$ = 45.3 meters per min.

Step-counter.

	Reading.
At end of 1 min.	91617
At end of 11 min.	92047
For 10 min.	430 x 2 = 860 steps or 86.0 steps per min.

Step-lift counter.

	Reading
At end of 1 min. 10 sec.	64748.5
At end of 11 min. 10 sec.	64852.9
For 10 min.	104.4 x 0.393 meter = 41.0 meters or 4.10 meters per min.

Rectal temperature record.

Time.	Bridge.	Temperature.	Remarks.
9:45 a.m.	---	--------	Thermometer inserted.
9:55 a.m.	200	36.48° C.	Standing.
10:00 a.m.	---	--------	Started walking.
10:05 a.m.	209	36.62° C.	---------------
10:13 a.m.	---	--------	Period began.
10:16 a.m.	235	37.02° C.	------------
10:20 a.m.	246	37.19° C.	------------
10:23 a.m.	255	37.35° C.	------------

Pulse record.

Time.	Beats.	Seconds.	Rate.	Remarks.
9:56:30 a.m.	73	61	71.8	Standing.
10:13:00 a.m.	--	--	----	Period began.
10:15:00 a.m.	136	64	127.5	Walking.
10:18:30 a.m.	66	30	132.0	Walking.
10:23:30 a.m.	133	59	135.3	Walking.
			131.6 average for walking.	

SUBJECTS.

Eight subjects were used in this study of the effect of muscular work upon the metabolism, but the greater part of the material was collected with two men, E. D. B. and W. K. A general description of these subjects follows. The body-surfaces were obtained by means of the height-weight chart of the Du Boises.[1] Experiments were made with still another subject (T. J. L.), but as he found difficulty in breathing through the mouthpiece and the results obtained with him were obviously erroneous, the data have not been included in this report.

A. J. O.—Born September 1884; age 30 years; height 180 cm.; nude weight 69.5 kg.; body-surface 1.88 sq. meters. Had previously served as subject in experiments at the Nutrition Laboratory. No trade or special training, but was of athletic build and with some experience as a professional ball-player. Discontinued experiments with him early in the research, as he was unreliable in his engagements.

H. R. R.—Born March 13, 1896; age 19 years; height 185 cm.; nude weight 70 kg.; body-surface 1.93 sq. meters. Student at Harvard University. Not especially interested in sports. Somewhat ungainly in movements and not "easy going" in his walk. Had a tendency to stoop and was of a nervous temperament. While he was anxious and willing to cooperate in every way, his duties at college made it difficult to use his services as much as would otherwise have been possible.

---

[1] Du Bois and Du Bois, Arch. Intern. Med., 1916, **17**, p. 863.

T. H. H.—Born September 2, 1886; age 29 years; height 171 cm.; nude weight 54.5 kg.; body-surface 1.63 sq. meters. Occupation, gardener. An Englishman, but recently arrived in this country, and without a situation. Served as subject but a few weeks, as he secured permanent work at his regular occupation. Slow and awkward in movements, but showed a desire to cooperate in the experiments.

W. K.—Born December 24, 1885; age 29 years; height 162 cm.; nude weight 49.2 kg.; body-surface 1.51 sq. meters. No trade, but had served as waiter in a restaurant. Satisfactory and reliable; during a part of the research the experiments were made with this subject only, as it was difficult to find suitable men. Stocky, well-built, easy walker, possessed a considerable amount of grit, and fulfilled each requirement to the best of his ability.

E. D. B.—Born October 23, 1892; age 23 years; height 173 cm.; nude weight 57 kg.; body-surface 1.68 sq. meters.[1] Quiet and phlegmatic. Had lived in a country town, and though not athletic, was well-built and accustomed to walking. After a few months' service, he suffered from a strained tendon in his foot; his use as a subject was accordingly discontinued until the lameness disappeared (January 6 to 30, 1916, inclusive). Examined on May 2, 1916, by a physician, who reported that "the heart sounds were of good quality; no murmurs heard; heart entirely normal."

While E. D. B. was incapacitated, the standing and walking tests were continued by using volunteer subjects from the Laboratory staff, all of whom had assisted in the experiments. These men were:

J. H. G.—Born April 21, 1895; age 20 years; height 185 cm.; nude weight 68.0 kg.; body-surface 1.89 sq. meters.

E. L. F.—Born November 27, 1892; age 23 years; height 171 cm.; nude weight 70.4 kg.; body-surface 1.82 sq. meters.

H. M. S.—Born August 31, 1868; age 48 years; height 180 cm.; nude weight 60.4 kg.; body-surface 1.78 sq. meters.

STATISTICS OF EXPERIMENTS.

The statistical data obtained in this study appear in chronological order for each subject in tables 3 to 16*a*. Metabolism measurements were made on some 225 days in all, with a total of approximately 1,300 experimental periods. These experiments were all carried out in the forenoon, with the subject in the post-absorptive condition, i. e., approximately 12 hours after the last meal. The experimental periods were usually about 12 minutes in duration, except for the severer grades of walking, when the time was reduced to 10 minutes and, in a few instances, to 8 minutes.

All of the results secured are given in the tables and represent the gross outlay in the energy output. With the exception of one day when the subject was psychically stimulated, no figures were excluded from the averages except in case of manifest error. Such exclusions have been indicated by inclosing the figures in parentheses. The averages for the different days are the averages of the results obtained for the periods on the individual days, except in the case of the respiratory quotient and the heat-output, these two values being recalculated from the average carbon dioxide and oxygen. The total averages for the subjects were obtained by averaging the daily averages and not by averaging the data for the individual periods.

---

[1] For additional data regarding surface area, see paper by Benedict (Am. Journ. Physiol., 1916, **41**, p. 275) in which photograph, silhouettes, and measurements are given of E. D. B. as Subject 7.

Table 3.—*Metabolism of A. J. O. and H. R. R., standing, in experiments without food. (Values per minute.)*

Date.	Average respiration-rate.	Average pulmonary ventilation (reduced).	Average pulse-rate.	Carbon dioxide.	Oxygen.	Respiratory quotient.	Heat (computed).
A. J. O.							
1915.		*liters.*		*c. c.*	*c. c.*		*cals.*
Feb. 15.....	20.8	7.4	....	242	265	0.92	....
	22.6	7.6	....	228	281	.81	....
	21.3	7.8	....	222	271	.82	....
Average...	21.6	7.6	....	231	272	.85	1.32
Feb. 24......	20.2	7.8	....	235	270	.87	....
	21.1	8.3	....	226	269	.84	....
	20.0	7.7	....	224	261	.86	....
	20.7	7.9	....	227	265	.86	....
Average...	20.5	7.9	....	228	266	.86	1.30
Feb. 27......	23.3	8.0	....	223	268	.84	....
	23.3	8.0	....	215	276	.78	....
Average...	23.3	8.0	....	219	272	.81	1.31
Gen. av. (3 days)...	21.8	7.8	....	226	270	.84	1.31
H. R. R.							
1915.							
Mar. 20.....	20.5	12.1	....	259	327	.80	....
	21.0	11.5	107	230	310	.74	....
	20.4	11.6	109	234	322	.73	....
Average...	(20.6)	(11.7)	(108)	(241)	(320)	(.75)	(1.52)
Apr. 10......	16.6	8.1	99	247	306	.81	....
	14.9	6.9	96	194	271	.72	....
	15.1	7.1	95	212	270	.79	....
	15.4	7.0	94	228	291	.79	....
	15.1	7.0	91	225	295	.77	....
Average...	15.4	7.2	95	221	287	.77	1.37
Apr. 17......	15.8	6.9	92	209	273	.77	....
	15.6	6.7	93	210	273	.77	....
	15.2	6.5	....	210	272	.78	....
	15.2	6.6	88	214	276	.78	....
Average...	15.5	6.7	91	211	274	.77	1.31
Gen. av.[1] (2 days).	15.5	7.0	93	216	281	.77	1.34

[1] For Apr. 10 and 17, 1915.

TABLE 4.—*Metabolism of T. H. H., standing, in experiments without food. (Values per minute.)*

Date.	Average respiration-rate.	Average pulmonary ventilation (reduced).	Average pulse-rate.	Carbon dioxide.	Oxygen.	Respiratory quotient.	Heat (computed).
1915.		*liters.*		*c. c.*	*c. c.*		*cals.*
Feb. 25..........	12.5	5.2	....	(217)	221	(0.98)	....
	12.9	5.0	....	199	227	.88	....
Average...	12.7	5.1	....	199	224	.89	1.10
Mar. 19..........	11.3	6.8	97	196	226	.87	....
	13.5	7.5	....	200	243	.82	....
	13.3	7.3	103	189	242	.78	....
Average...	12.7	7.2	100	195	237	.82	1.14
Mar. 22..........	13.1	7.2	87	201	224	.90	....
	13.0	7.0	90	189	216	.88	....
	13.6	7.3	96	196	223	.88	....
Average...	13.2	7.2	91	195	221	.88	1.08
Gen. av. (3 days)...	12.9	6.5	96	196	227	.86	1.11

TABLE 5.—*Metabolism of W. K., standing, in experiments without food. (Values per minute.)*

Date.	Average respiration-rate.	Average pulmonary ventilation (reduced).	Average pulse-rate.	Carbon dioxide.	Oxygen.	Respiratory quotient.	Heat (computed).
1915.		*liters.*		*c. c.*	*c. c.*		*cals.*
Feb. 26..........	21.3	7.0	....	185	209	0.89	....
	23.1	6.7	....	179	214	.84	....
	23.1	6.1	....	176	214	.83	....
Average...	22.5	6.6	....	180	212	.85	1.03
Mar. 11..........	20.3	5.5	78	170	(281)	(.61)	....
	20.9	5.8	80	168	235	.72	....
	22.5	6.4	78	183	233	.79	....
Average...	21.2	5.9	79	174	234	.74	1.11
Mar. 12..........	27.0	6.7	....	186	225	.83	....
	26.6	6.7	....	192	208	.93	....
	21.1	7.8	....	201	207	.98	....
Average...	24.9	7.1	....	193	213	.91	1.05

TABLE 5.—*Metabolism of W. K., standing, in experiments without food. (Values per minute.)*—Continued.

Date.	Average respiration-rate.	Average pulmonary ventilation (reduced).	Average pulse-rate.	Carbon dioxide.	Oxygen.	Respiratory quotient.	Heat (computed).
1915		*liters.*		*c. c.*	*c. c.*		*cals.*
Mar. 13.........	22.5	6.3	....	187	264	0.71	....
	24.1	8.2	....	211	262	.81	....
	24.5	7.7	....	201	234	.86	....
Average...	23.7	7.4	....	200	253	.79	1.21
Mar. 16.........	20.3	7.2	81	182	203	.90	....
	18.2	5.6	....	177	212	.84	....
	18.6	5.7	....	187	222	.85	....
Average...	19.0	6.2	81	182	212	.86	1.03
Mar. 17.........	17.1	5.6	87	187	261	.72	....
	18.1	5.8	82	186	253	.74	....
	19.2	5.6	77	196	(295)	(.67)	....
Average...	18.1	5.7	82	190	257	.74	1.21
Mar. 18.........	18.2	8.8	80	176	212	.83	....
	18.2	9.1	81	177	212	.84	....
	18.1	9.0	84	179	213	.85	....
Average...	18.2	9.0	82	177	212	.83	1.03
May 29.........	25.1	7.0	75	205	238	.86	....
	21.7	6.3	73	194	235	.83	....
	21.4	6.4	74	194	224	.87	....
Average...	22.7	6.6	74	198	232	.85	1.13
June 1..........	20.6	6.6	86	182	212	.86	....
	19.1	6.2	85	(266)	213	(1.25)	....
	18.8	6.1	81	193	219	.89	....
	19.3	6.3	87	194	209	.93	....
Average...	19.5	6.3	85	190	213	.89	1.05
June 2..........	20.2	9.8	81	191	224	.85	....
	22.8	10.7	78	189	236	.81	....
	21.1	10.2	....	181	233	.78	....
Average...	21.4	10.2	80	187	231	.81	1.11
June 3..........	22.0	10.4	79	177	231	.77	....
	22.7	10.7	78	189	237	.80	....
	22.4	10.6	79	189	238	.80	....
Average...	22.4	10.6	79	185	235	.79	1.13
June 4..........	20.4	9.6	....	177	218	.82	....
	19.7	9.6	....	189	241	.79	....
	23.6	10.6	74	183	238	.77	....
Average...	21.2	9.9	74	183	232	.79	1.11

TABLE 5.—*Metabolism of W. K., standing, in experiments without food.* (*Values per minute.*)—Continued.

Date.	Average respiration-rate.	Average pulmonary ventilation (reduced).	Average pulse-rate.	Carbon dioxide.	Oxygen.	Respiratory quotient.	Heat (computed).
1915		*liters.*		*c. c.*	*c. c.*		*cals.*
June 5...........	20.7	9.5	....	181	233	0.78	....
	20.9	9.9	....	201	250	.81	....
	22.0	10.3	....	199	247	.81	....
Average...	21.2	9.9	....	194	243	.80	1.17
June 14..........	20.8	9.6	78	182	224	.81	....
	19.8	9.3	....	176	209	.85	....
	18.8	8.9	74	171	203	.85	....
Average...	19.8	9.3	76	176	212	.83	1.03
Gen. av. (14 days)	21.1	[1]6.5	79	186	228	.82	1.10

[1] March 18, and June 2 to 14, inclusive, omitted from average.

TABLE 6.—*Metabolism of E. D. B., standing, in experiments without food.* (*Values per minute.*)

Date.	Average respiration-rate.	Average pulmonary ventilation (reduced).	Average pulse-rate.	Carbon dioxide.	Oxygen.	Respiratory quotient.	Heat (computed).
1915.		*liters.*		*c. c.*	*c. c.*		*cals.*
Oct. 4...........	11.5	8.2	....	204	237	0.86	....
	12.1	8.3	....	212	266	.80	....
	13.3	8.8	....	204	250	.82	....
Average...	12.3	8.4	....	207	251	.82	1.21
Oct. 6...........	13.2	8.4	....	191	240	.80	....
	12.9	8.5	....	197	247	.80	....
	13.1	8.4	....	190	247	.77	....
	12.1	8.3	....	201	250	.80	....
	12.8	8.3	....	192	237	.81	....
Average...	12.8	8.4	....	194	244	.80	1.17
Oct. 8...........	13.3	8.3	....	190	239	.80	....
	13.4	8.2	....	192	235	.82	....
	13.2	8.2	....	191	252	.76	....
	14.7	8.6	....	190	245	.78	....
	13.6	8.2	....	186	230	.81	....
Average...	13.6	8.3	....	190	240	.79	1.15
Oct. 9...........	13.3	8.2	....	189	254	.74	....
	14.1	8.5	....	190	242	.79	....
	14.5	8.7	....	190	253	.75	....
Average...	14.0	8.5	....	190	250	.76	1.19

Table 6.—*Metabolism of E. D. B., standing, in experiments without food. (Values per minute.)*—Continued.

Date.	Average respiration-rate.	Average pulmonary ventilation (reduced)	Average pulse-rate.	Carbon dioxide.	Oxygen.	Respiratory quotient.	Heat (computed).
1915		*liters.*		*c. c.*	*c. c.*		*cals.*
Oct. 11..........	14.5	8.7	....	199	223	0.90	....
	15.0	9.2	....	206	241	.85	....
	15.2	9.2	....	197	230	.86	....
Average...	14.9	9.0	....	201	231	.87	1.13
Oct. 13..........	14.4	8.2	....	172	225	.76	....
	14.8	8.8	....	190	242	.79	....
	14.8	9.0	....	191	238	.81	....
Average...	14.7	8.7	....	184	235	.78	1.12
Oct. 14..........	14.2	9.0	....	192	233	.82	....
	14.4	9.0	....	189	235	.81	....
	14.5	8.9	....	185	234	.79	....
Average...	14.4	9.0	....	189	234	.81	1.13
Oct. 15..........	13.9	8.6	....	183	231	.79	....
	15.3	9.4	....	187	231	.81	....
	15.2	9.2	....	181	228	.80	....
Average...	14.8	9.1	....	184	230	.80	1.10
Oct. 16..........	14.3	8.7	....	187	222	.84	....
	15.9	9.4	....	188	211	.89	....
	15.2	9.2	....	192	219	.88	....
Average...	15.1	9.1	....	189	217	.87	1.06
Oct. 18..........	15.0	9.4	....	204	238	.86	....
	15.2	9.3	....	188	225	.84	....
	14.9	9.2	....	196	224	.88	....
Average...	15.0	9.3	....	196	229	.86	1.12
Oct. 19..........	16.0	9.3	....	190	235	.81	....
	15.5	9.2	....	188	246	.77	....
	15.8	9.4	....	191	236	.81	....
Average...	15.8	9.3	....	190	239	.80	1.14
Oct. 20..........	16.0	9.6	....	196	240	.82	....
	16.1	9.4	....	186	222	.84	....
	16.5	10.0	....	202	240	.84	....
Average...	16.2	9.7	....	195	234	.83	1.13
Oct. 21..........	15.3	9.1	....	185	220	.84	....
	16.0	9.6	....	194	232	.84	....
	16.2	9.5	....	189	216	.88	....
Average...	15.8	9.4	....	189	223	.85	1.08

TABLE 6.—*Metabolism of E. D. B., standing, in experiments without food. (Values per minute.)*—Continued.

Date.	Average respiration-rate.	Average pulmonary ventilation. (reduced).	Average pulse-rate.	Carbon dioxide.	Oxygen.	Respiratory quotient.	Heat (computed).
1915		*liters.*		*c. c.*	*c. c.*		*cals.*
Oct. 22..........	16.6	9.7	....	196	222	0.89	....
	15.8	9.2	....	180	213	.85	....
	16.0	9.3	....	185	216	.86	....
Average...	16.1	9.4	....	187	217	.86	1.06
Oct. 23..........	15.4	8.8	....	177	218	.81	....
	16.0	9.4	....	188	227	.83	....
	16.4	9.6	....	187	221	.85	....
Average...	15.9	9.3	....	184	222	.83	1.07
Oct. 25..........	15.7	9.2	....	196	214	.92	....
	16.5	9.7	....	194	213	.92	....
	16.0	9.5	....	196	227	.87	....
Average...	16.1	9.5	....	195	218	.90	1.07
Oct. 26..........	17.1	9.5	....	189	217	.87	....
	16.1	9.4	....	186	212	.88	....
	16.4	9.6	....	183	224	.82	....
Average...	16.5	9.5	....	186	218	.85	1.06
Oct. 27..........	15.4	8.9	....	181	226	.80	....
	16.7	9.4	....	181	216	.84	....
	15.6	9.2	....	182	224	.81	....
Average...	15.9	9.2	....	181	222	.82	1.07
Oct. 28..........	15.4	8.8	....	182	215	.85	....
	15.6	9.2	....	187	229	.82	....
	15.7	9.3	....	194	224	.87	....
Average...	15.6	9.1	....	188	223	.84	1.08
Oct. 29..........	15.2	8.6	....	180	219	.82	....
	15.8	9.1	....	188	228	.83	....
	15.4	8.9	....	186	229	.81	....
Average...	15.5	8.9	....	185	225	.82	1.09
Nov. 18..........	14.4	6.1	....	183	207	.88	....
	14.8	6.3	....	182	206	.89	....
	14.6	6.2	....	181	205	.88	....
Average...	14.6	6.2	....	182	206	.88	1.01
Nov. 19..........	14.2	6.1	....	190	211	.90	....
	15.3	6.3	....	177	208	.85	....
	14.7	6.4	....	180	207	.87	....
Average...	14.7	6.3	....	182	209	.87	1.02

Table 6.—*Metabolism of E. D. B., standing, in experiments without food. (Values per minute.)*—Continued.

Date.	Average respiration-rate.	Average pulmonary ventilation (reduced).	Average pulse-rate.	Carbon dioxide.	Oxygen.	Respiratory quotient.	Heat (computed).
1915.		*liters.*		*c. c.*	*c. c.*		*cals.*
Nov. 27.........	15.4	8.9	....	199	216	0.93	....
	16.1	9.4	....	....	222	....	....
	16.0	9.4	....	208	224	.93	....
Average...	15.8	9.2	....	204	221	.92	1.09
Nov. 29.........	16.7	9.3	82	188	219	.86	....
	16.8	9.4	....	188	213	.89	....
	16.6	9.6	....	198	225	.88	....
Average...	16.7	9.4	82	191	219	.87	1.07
Nov. 30.........	16.5	9.4	74	195	218	.90	....
	16.1	9.3	....	192	223	.86	....
	16.5	9.6	....	204	235	.87	....
Average...	16.4	9.4	74	197	225	.88	1.10
Dec. 21.........	14.7	8.7	....	187	194	.97	....
	15.1	9.1	58	193	212	.91	....
	14.6	8.8	....	191	214	.90	....
Average...	14.8	8.9	58	190	207	.92	1.02
Dec. 22.........	12.6	7.7	....	184	217	.85	....
	12.9	8.2	....	195	219	.89	....
Average...	12.8	8.0	....	190	218	.87	1.07
Dec. 31.........	14.6	8.9	....	193	242	.80	....
	15.4	9.8	71	218	263	.83	....
	15.7	10.3	78	222	265	.84	....
Average...	15.2	9.7	75	211	257	.82	1.24
1916.							
Jan. 3.........	16.0	9.5	....	199	229	.87	....
	15.0	9.5	....	222	262	.85	....
	15.8	9.5	....	209	258	.81	....
Average...	15.6	9.5	....	210	250	.84	1.21
Jan. 4.........	14.1	8.8	....	198	236	.84	....
	15.1	9.6	....	216	242	.89	....
	15.8	10.2	....	223	253	.88	....
Average...	15.0	9.5	....	212	244	.87	1.19
Jan. 5.........	14.8	8.7	85	199	251	.79	....
	15.6	9.4	80	210	249	.84	....
	16.2	9.3	78	208	259	.80	....
Average...	15.5	9.1	81	206	253	.81	1.22

TABLE 6.—*Metabolism of E. D. B., standing, in experiments without food. (Values per minute.)*—Continued.

Date.	Average respiration-rate.	Average pulmonary ventilation (reduced).	Average pulse-rate.	Carbon dioxide.	Oxygen.	Respiratory quotient.	Heat (computed).
1916.		*liters.*		*c. c.*	*c. c.*		*cals.*
Jan. 31..........	15.4	9.0	95	197	232	0.85	....
	14.6	9.0	89	198	247	.80	....
	16.1	9.5	88	194	244	.80	....
Average...	15.4	9.2	91	196	241	.81	1.16
Feb. 1...........	15.5	9.6	96	220	277	.79	....
	16.6	10.0	95	221	267	.83	....
	16.9	10.1	93	217	261	.83	....
Average...	16.3	9.9	95	219	268	.82	1.29
Feb. 12..........	14.4	8.8	65	191	244	.78	1.17
Feb. 14..........	14.9	9.2	77	196	240	.82	1.16
Feb. 15..........	16.2	10.1	79	207	261	.79	1.25
Feb. 16..........	15.5	9.4	....	205	255	.80	1.22
Feb. 17..........	16.5	10.0	85	210	267	.79	1.28
Feb. 18..........	15.7	9.5	76	205	264	.78	1.26
Feb. 19..........	13.3	8.2	52	208	243	.86	1.18
Feb. 21..........	15.7	10.0	78	225	268	.84	1.30
Feb. 22..........	15.7	10.0	76	217	245	.89	1.20
Feb. 23..........	15.8	9.5	73	214	288	.74	1.36
Feb. 24..........	15.0	9.5	73	214	254	.84	....
	15.4	9.8	76	216	255	.85	....
Average...	15.2	9.7	75	215	255	.84	1.24
Feb. 25..........	15.8	9.4	71	208	238	.87	....
	16.1	9.7	71	210	258	.81	....
Average...	16.0	9.6	71	209	248	.84	1.20
Feb. 26..........	15.7	9.1	67	212	244	.87	....
	16.5	9.7	72	212	258	.82	....
Average...	16.1	9.4	70	212	251	.84	1.22
Feb. 28..........	14.4	9.0	....	225	239	.94	....
	15.2	8.9	68	206	238	.87	....
	15.6	9.5	70	209	255	.82	....
Average...	15.1	9.1	69	213	244	.87	1.19
Feb. 29..........	15.0	9.0	69	182	225	.81	....
	14.3	8.4	66	183	229	.80	....
	15.1	9.0	69	185	237	.78	....
Average...	14.8	8.8	68	183	230	.80	1.10
Mar. 1..........	14.6	8.8	....	198	222	.89	....
	14.5	9.1	....	202	234	.86	....
	14.0	8.7	....	197	238	.83	....
Average...	14.4	8.9	....	199	231	.86	1.13

Table 6.—*Metabolism of E. D. B., standing, in experiments without food. (Values per minute.)*—Continued.

Date.	Average respiration-rate.	Average pulmonary ventilation (reduced).	Average pulse-rate.	Carbon dioxide.	Oxygen.	Respiratory quotient.	Heat (computed).
1916.		*liters.*		*c. c.*	*c. c.*		*cals.*
Mar. 2..........	15.7	9.3	78	202	236	0.86	....
	16.1	9.4	78	192	239	.81	....
	14.9	9.0	80	198	244	.81	....
	15.5	9.0	81	187	229	.82	....
	16.0	9.2	82	185	....	....	....
	15.3	9.2	76	192	243	.79	....
Average...	15.6	9.2	79	193	238	.81	1.15
Mar. 3..........	15.0	8.7	76	186	240	.78	....
	15.7	9.3	74	194	244	.80	....
	16.1	9.5	76	197	241	.82	....
	15.9	9.3	71	191	246	.78	....
	15.8	9.2	76	185	233	.80	....
	15.9	9.2	73	186	241	.78	....
Average...	15.7	9.2	74	190	241	.79	1.15
Mar. 20..........	14.8	9.4	80	219	276	.80	....
	16.0	9.8	82	215	272	.79	....
	16.4	9.6	81	206	259	.80	....
Average...	15.7	9.6	81	213	269	.79	1.29
Mar. 22..........	15.6	9.0	83	201	248	.81	....
	16.5	9.4	81	206	255	.81	....
	16.2	9.2	79	201	258	.78	....
Average...	16.1	9.2	81	203	254	.80	1.22
Mar. 23..........	16.1	9.2	77	201	249	.81	....
	15.9	9.0	73	196	251	.78	....
	16.1	9.0	73	196	252	.78	....
Average...	16.0	9.1	74	198	251	.79	1.20
Mar. 24..........	16.2	9.1	77	216	242	.89	....
	16.6	9.7	76	216	264	.82	....
	15.9	9.1	74	200	256	.78	....
Average...	16.2	9.3	76	211	254	.83	1.23
Mar. 29..........	15.4	8.9	79	201	255	.79	....
	15.9	9.2	82	200	267	.75	....
	16.1	9.4	83	204	272	.75	....
Average...	15.8	9.2	81	202	265	.76	1.26
Mar. 30..........	16.5	9.4	84	200	243	.83	....
	15.8	9.1	83	198	251	.79	....
	16.5	9.6	83	200	251	.80	....
Average...	16.3	9.4	83	199	248	.80	1.19

TABLE 6.—*Metabolism of E. D. B., standing, in experiments without food.* (*Values per minute.*)—Continued.

Date.	Average respiration-rate.	Average pulmonary ventilation (reduced).	Average pulse-rate.	Carbon dioxide.	Oxygen.	Respiratory quotient.	Heat (computed).
1916.		*liters.*		*c. c.*	*c. c.*		*cals.*
Mar. 31.........	15.9	9.1	79	201	242	0.84	....
	16.5	9.5	81	202	256	.79	....
	16.2	9.4	78	193	243	.80	....
Average...	16.2	9.3	79	199	247	.81	1.19
Apr. 1...........	16.2	9.0	82	199	238	.84	....
	16.4	9.4	80	198	235	.85	....
	16.7	9.4	79	194	241	.81	....
Average...	16.4	9.3	80	197	238	.83	1.15
Apr. 3...........	15.2	9.3	77	212	248	.86	....
	15.9	9.3	75	205	245	.84	....
	15.8	9.3	76	201	247	.81	....
Average...	15.6	9.3	76	206	247	.83	1.19
Apr. 4...........	15.4	9.2	84	200	237	.84	....
	15.5	9.0	81	194	224	.87	....
	15.9	9.3	85	195	239	.82	....
Average...	15.6	9.2	83	196	233	.84	1.13
Apr. 5...........	15.7	9.1	91	202	247	.82	....
	15.7	9.1	90	188	239	.79	....
	16.3	9.3	90	194	250	.78	....
Average...	15.9	9.2	90	195	245	.80	1.18
Apr. 6...........	15.1	9.0	89	203	257	.79	....
	15.7	9.2	86	195	238	.82	....
	16.3	9.4	83	196	237	.83	....
Average...	15.7	9.2	86	198	244	.81	1.17
Apr. 7...........	14.8	8.8	79	186	238	.78	....
	14.9	8.9	79	200	246	.82	....
	15.4	9.0	82	194	242	.80	....
Average...	15.0	8.9	80	193	242	.80	1.16
Apr. 8...........	15.3	9.4	81	224	251	.89	....
	15.2	9.0	79	204	241	.85	....
	15.2	9.0	79	195	240	.82	....
Average...	15.2	9.1	80	208	244	.85	1.19
Apr. 10..........	14.8	9.0	80	214	233	.92	....
	15.4	9.3	82	216	237	.91	....
Average...	15.1	9.2	81	215	235	.91	1.16

TABLE 6.—*Metabolism of E. D. B., standing, in experiments without food. (Values per minute.)*—Continued.

Date.	Average respiration-rate.	Average pulmonary ventilation (reduced).	Average pulse-rate.	Carbon dioxide.	Oxygen.	Respiratory quotient.	Heat (computed).
1916.		*liters.*		*c. c.*	*c. c.*		*cals.*
Apr. 11..........	15.1	8.9	84	207	228	0.91	....
	14.8	8.9	77	202	241	.84	....
	15.1	9.1	82	199	249	.80	....
Average...	15.0	9.0	81	203	239	.85	1.16
Apr. 12..........	15.5	9.1	86	200	245	.82	....
	15.5	9.0	86	191	246	.78	....
	15.6	9.4	79	202	270	.75	....
Average...	15.5	9.2	84	198	254	.78	1.21
Apr. 13..........	15.8	9.2	83	203	232	.88	....
	15.6	9.2	82	201	233	.87	....
	16.0	9.6	80	211	252	.84	....
Average...	15.8	9.3	82	205	239	.86	1.17
Apr. 14..........	15.1	9.0	80	218	246	.89	....
	15.4	8.9	82	200	233	.86	....
	15.8	9.2	82	204	235	.87	....
Average...	15.4	9.0	81	207	238	.87	1.16
Apr. 15..........	15.5	9.2	80	203	242	.84	....
	15.9	9.3	81	201	235	.86	....
	16.0	9.3	81	197	241	.82	....
Average...	15.8	9.3	81	200	239	.84	1.16
Gen. av. (71 days)	15.4	9.1	78	199	240	.83	1.16

TABLE 6*a*.—*Average body-temperature and blood-pressure of E. D. B., standing, in experiments without food. (Values per minute.)*

Date.	Average body-temperature.	Date.	Average body-temperature.	Blood-pressure.	Date.	Average body-temperature.	Blood-pressure.
1916.	°*C.*	1916.	°*C.*	*mm.*	1916.	°*C.*	*mm.*
Jan. 5.........	36.89	Jan. 31.........	37.26	......	Feb. 1.........	37.29	......
	36.94		37.22	......		37.27	......
	36.89		37.19	......		37.19	......
Average...	36.91	Average...	37.22	......	Average...	37.25	......
					Feb. 12........	36.80	......
					Feb. 14........	37.10	......

Table 6a.—*Average body-temperature and blood-pressure of E. D. B., standing, in experiments without food. (Values per minute.)*—Continued.

Date.	Average body-temperature.	Blood-pressure.
1916.	*°C.*	
Feb. 15	36.94	
Feb. 16	36.88	
Feb. 17	37.13	
Feb. 18	37.21	
Feb. 19	36.36	
Feb. 21	37.01	
Feb. 22	36.94	
Feb. 23	37.25	
Feb. 24	36.94	
	36.95	
Average	36.95	
Feb. 25	37.06	
	37.07	
Average	37.07	
Feb. 26	36.99	
	37.02	
Average	37.01	
Feb. 28	36.67	
	36.75	
	36.81	
Average	36.74	
Feb. 29	36.76	
	36.64	
	36.69	
Average	36.70	
Mar. 2	36.53	
	36.59	
	36.50	
	36.62	
	36.62	
	36.68	
Average	36.59	
Mar. 3	36.52	
	36.59	
	36.31	
	36.43	
	36.36	
	36.45	
Average	36.44	
1916.	*°C.*	*mm.*
Mar. 20	36.57	112
	36.62	114
	36.60	115
Average	36.60	114
Mar. 22	36.62	111
	36.96	110
	37.05	110
Average	36.88	110
Mar. 23	37.11	113
	37.08	113
	37.09	115
Average	37.09	114
Mar. 24	37.49	117
	37.23	121
	37.27	121
Average	37.33	120
Mar. 29	36.84	106
	36.63	111
	36.68	111
Average	36.72	109
Mar. 30	37.03	111
	37.09	115
	37.08	113
Average	37.07	113
Mar. 31	36.64	119
	36.59	122
	36.77	118
Average	36.67	120
Apr. 1	36.78	113
	36.75	115
	36.68	118
Average	36.74	115
Apr. 3	36.32	116
	36.82	117
	36.89	115
Average	36.68	116
Apr. 4	36.94	110
	36.88	114
	36.68	115
Average	36.83	113
1916.	*°C.*	*mm.*
Apr. 5	37.00	119
	36.91	118
	36.95	117
Average	36.95	118
Apr. 6	36.88	117
	36.83	116
	36.82	115
Average	36.84	116
Apr. 7	36.62	118
	36.41	120
	36.45	120
Average	36.49	119
Apr. 8	36.66	122
	36.65	127
	36.69	126
Average	36.67	125
Apr. 10	37.09	121
	36.99	120
Average	37.04	121
Apr. 11	36.85	118
	36.82	116
	36.84	119
Average	36.84	118
Apr. 12	36.99	118
	36.98	117
	36.89	118
Average	36.95	118
Apr. 13	36.94	115
	36.91	118
	36.93	117
Average	36.93	117
Apr. 14	36.92	116
	36.99	115
	37.01	118
Average	36.97	116
Apr. 15	36.95	116
	36.93	119
	36.98	119
Average	36.95	118
Gen. av.	[1]36.89	[2]117

[1] For 40 days.

[2] For 20 days.

TABLE 7.—*Metabolism of J. H. G., E. L. F., and H. M. S., standing, in experiments without food. (Values per minute.)*

Date.	Average respiration-rate.	Average pulmonary ventilation (reduced).	Average pulse-rate.	Carbon dioxide.	Oxygen.	Respiratory quotient.	Heat (computed).
J. H. G. 1916.		*liters.*		*c. c.*	*c. c.*		*cals.*
Jan. 18..........	13.4	9.5	113	225	269	0.84	....
	16.1	10.5	120	228	284	.80	....
	17.7	11.5	....	243	310	.79	....
Average...	15.7	10.5	117	232	288	.81	1.39
Jan. 19..........	15.0	9.3	....	208	271	.77	....
	16.2	10.3	106	191	262	.73	....
	16.5	10.6	....	217	280	.78	....
Average...	15.9	10.1	106	205	271	.76	1.29
Jan. 20..........	16.6	11.0	102	226	278	.82	....
	17.4	11.4	....	226	267	.85	....
	17.5	11.5	109	222	285	.78	....
Average...	17.2	11.3	106	225	277	.81	1.33
Gen. av. (3 days)...	16.3	10.6	110	221	279	.79	1.34
E. L. F.							
Jan. 21..........	12.8	9.4	97	230	295	.78	....
	16.8	10.7	100	219	293	.75	....
	15.7	10.4	93	217	264	.82	....
Average...	15.1	10.2	97	222	284	.78	1.36
Jan. 22..........	11.8	9.8	....	241	269	.90	....
	11.8	9.4	....	228	249	.92	....
	13.7	9.6	....	216	253	.86	....
Average...	12.4	9.6	....	228	257	.89	1.26
Jan. 24..........	18.1	11.5	112	205	249	.83	....
	17.2	12.0	119	220	250	.88	....
	17.3	12.6	117	241	263	.92	....
Average...	17.5	12.0	116	222	254	.87	1.24
Gen. av. (3 days)...	15.0	10.6	107	224	265	.85	1.29
H. M. S.							
Jan. 25..........	17.8	10.3	97	183	226	.81	....
	17.0	9.9	97	179	248	.73	....
	16.6	9.9	98	189	241	.79	....
Average...	17.1	10.0	97	184	238	.77	1.13
Jan. 26..........	17.0	9.9	86	182	242	.76	....
	16.4	9.9	87	184	237	.78	....
	16.8	10.1	86	186	224	.83	....
Average...	16.7	10.0	86	184	234	.79	1.12
Gen. av. (2 days)...	16.9	10.0	92	184	236	.78	1.13

TABLE 8.—*Metabolism of A. J. O. and H. R. R. during horizontal walking in experiments without food. (Values per minute.)*

Date.	Distance.	Average respiration-rate.	Average pulmonary ventilation (reduced).	Average pulse-rate.	No. of steps.	Carbon dioxide.	Oxygen.	Respiratory quotient.	Heat (computed).
A. J. O. 1915.	*meters.*		*liters.*			*c. c.*	*c. c.*		*cals.*
Feb. 15	[1]63.1	24.2	13.8	....	....	585	672	0.87	3.28
Feb. 24	63.1	23.7	19.3	....	96.9	627	758	.83	3.67
	63.8	24.5	14.9	....	96.8	619	750	.83	3.63
Average	63.5	24.1	17.1	....	96.9	623	754	.83	3.65
Mar. 2	63.8	22.2	14.5	....	98.7	635	735	.87	3.58
	60.7	22.5	14.0	....	93.8	584	694	.84	3.37
	63.6	25.4	19.6	....	97.9	598	665	.90	3.27
Average	62.7	23.4	16.0	....	96.8	606	698	.87	3.41
Gen. av. (3 days)	63.1	23.9	15.6	....	96.9	605	708	.85	3.45
H. R. R. 1915.									
Mar. 20	67.7	18.1	16.8	115	105.4	812	1,017	.80	4.88
	64.5	18.1	15.6	126	102.2	740	936	.79	4.48
Average	66.1	18.1	16.2	121	103.8	776	977	.80	4.69
Mar. 27	65.8	17.4	16.5	106	102.8	756	888	.85	4.32
	67.2	18.0	16.1	107	102.6	724	896	.81	4.31
	67.5	18.3	16.2	111	102.4	725	908	.80	4.36
Average	66.8	17.9	16.3	108	102.6	735	897	.82	4.33
Apr. 3	60.9	15.5	15.0	104	95.2	694	837	.83	4.05
	60.5	17.8	15.1	110	95.0	688	852	.81	4.10
	60.0	18.4	15.7	113	95.6	688	857	.81	4.12
Average	60.5	17.2	15.3	109	95.3	690	849	.81	4.09
Apr. 10	61.1	17.9	16.0	101	99.0	718	887	.81	4.27
Apr. 17	60.0	16.6	14.0	....	98.4	667	799	.83	3.87
	59.9	16.1	14.4	100	97.8	664	....	.83	[2]3.87
Average	60.0	16.4	14.2	100	98.1	666	799	.83	3.87
Apr. 24	61.8	16.6	14.3	96	99.2	647	807	.80	3.87
	60.2	17.2	14.1	97	95.0	629	781	.81	3.76
	60.6	18.2	13.9	97	94.8	616	785	.79	3.76
	60.1	17.7	13.9	96	96.0	620	796	.80	3.82
Average	60.7	17.4	14.1	97	98.3	628	792	.80	3.80
Gen. av. (6 days)	62.5	17.5	15.4	106	99.5	702	867	.81	4.17

[1] Computed from averages for Feb. 24 and Mar. 2.

[2] Computed from the carbon dioxide for the period and the respiratory quotient for the day.

TABLE 9.—*Metabolism of T. H. H. during horizontal walking in experiments without food* (*Values per minute.*)

Date.	Distance.	Average respiration-rate.	Average pulmonary ventilation (reduced).	Average pulse-rate.	No. of steps.	Carbon dioxide.	Oxygen.	Respiratory quotient.	Heat (computed).
1915.	*meters.*		*liters.*			*c. c.*	*c. c.*		*cals.*
Feb. 25.........	63.4	....	12.6	....	100.7	518	624	0.83	3.02
	63.7	15.9	11.5	....	98.3	546	602	.91	2.98
	63.7	15.0	10.5	....	97.9	544	607	.90	2.99
Average....	63.6	15.5	11.5	....	99.0	536	611	.88	2.99
Mar. 19.........	65.7	14.9	12.0	98	107.0	595	710	.84	3.44
	66.7	16.8	11.7	103	106.4	571	715	.80	3.43
	67.1	16.7	11.5	106	106.2	562	733	.77	3.49
	67.8	15.3	11.4	108	106.0	561	713	.79	3.41
Average....	66.8	15.9	11.7	104	106.4	572	718	.80	3.45
Mar. 22.........	67.5	14.4	11.0	97	106.6	582	722	.81	3.47
	67.5	14.6	11.0	....	105.0	560	683	.82	3.30
Average....	67.5	14.5	11.0	97	105.8	571	703	.81	3.38
Mar. 24.........	67.4	14.3	11.2	....	104.8	588	685	.86	3.34
	68.1	14.4	11.2	....	104.2	574	(746)	(.77)	[1]3.22
	67.8	13.2	11.0	88	103.6	574	652	.88	3.19
Average....	67.8	14.0	11.1	88	104.2	579	669	.87	3.27
Mar. 26.........	65.9	15.3	11.6	88	100.8	613	671	.92	3.32
	67.6	14.2	11.0	88	101.2	572	(781)	(.73)	[1]3.18
	68.2	13.5	10.3	84	102.0	555	646	.86	3.15
Average....	67.2	14.3	11.0	87	101.3	580	659	.88	3.23
Mar. 30.........	65.9	13.8	12.0	....	102.0	607	683	.89	3.35
	66.8	13.4	12.1	....	102.2	596	695	.86	3.39
	63.5	14.4	11.7	93	99.8	560	675	.83	3.27
Average....	65.4	13.9	12.0	93	101.3	588	684	.86	3.33
Apr. 5	62.4	13.2	11.3	99	99.4	593	690	.86	3.36
	62.7	13.1	11.1	101	100.4	575	....	....	[1]3.35
	63.2	13.8	11.2	105	100.8	577	709	.82	3.42
Average....	62.8	13.4	11.2	102	100.2	582	700	.83	3.39
Gen. av. (7 days)	65.9	14.5	11.4	95	102.6	573	678	.85	3.30

[1] Calculated from the carbon dioxide for the period and the average respiratory quotient for the day.

TABLE 10.—*Metabolism of W. K. during horizontal walking in experiments without food. (Values per minute.)*

Date.	Distance.	Average respiration-rate.	Average pulmonary ventilation (reduced).	Average pulse-rate.	No. of steps.	Carbon dioxide.	Oxygen.	Respiratory quotient.	Heat (computed).
1915.	*meters.*		*liters.*			*c. c.*	*c. c.*		*cals.*
Feb. 18.........	65.6	19.2	10.8	....	112.6	431	629	0.69	2.95
	66.9	19.9	10.4	....	116.2	429	562	.77	2.68
	66.3	19.6	9.9	....	114.7	....	....	....	....
Average....	66.3	19.6	10.4	....	114.5	430	596	.72	2.80
Feb. 26.........	64.4	19.9	9.7	....	114.7	435	528	.82	2.55
Mar. 4........	64.0	21.4	14.8	....	115.4	(649)	621	(1.05)	[1]3.06
	62.9	22.1	13.3	....	113.0	543	606	.90	2.98
	66.0	21.0	13.1	....	115.2	561	625	.90	3.08
Average....	64.3	21.5	13.7	....	114.5	552	617	.90	3.04
Mar. 5........	65.3	20.6	11.9	....	115.3	532	596	.90	2.93
	65.9	22.7	11.6	....	114.4	508	582	.87	2.84
	66.2	23.8	11.8	....	115.2	505	593	.85	2.88
Average....	65.8	22.4	11.8	....	115.0	515	590	.87	2.88
Mar. 8........	66.4	23.2	12.2	....	116.6	511	618	.83	2.99
	66.6	26.8	12.9	....	116.0	498	590	.85	2.87
	66.6	27.0	12.2	....	115.6	486	584	.84	2.83
Average....	66.5	25.7	12.4	....	116.1	498	597	.83	2.89
Mar. 9........	66.0	24.1	11.1	....	115.6	533	615	.87	3.01
	62.5	26.0	10.7	....	108.6	436	553	.80	2.65
	62.2	24.2	10.2	....	109.0	433	....	....	[2]2.57
	58.6	23.7	11.2	....	107.6	421	511	.82	2.47
Average....	62.3	24.5	10.8	....	110.2	456	560	.81	2.70
Mar. 12........	60.9	24.6	10.8	....	111.2	452	593	.76	2.82
	58.5	25.0	10.4	....	109.8	431	512	.84	2.48
	68.2	22.9	11.0	....	117.6	491	565	.87	2.76
Average....	62.5	24.2	10.7	....	112.9	458	557	.82	2.69
Mar. 13........	65.1	18.6	11.0	....	114.0	477	598	.80	2.87
	64.7	18.7	10.6	....	113.0	455	583	.78	2.78
	59.4	19.4	10.4	....	108.0	437	606	.72	2.85
	59.1	20.1	11.2	....	107.4	451	544	.83	2.63
Average....	62.1	19.2	10.8	....	110.6	455	583	.78	2.78
Mar. 16........	59.2	21.3	11.1	74	109.8	461	558	.83	2.70
	62.3	20.5	11.0	77	112.4	452	546	.83	2.64
	60.9	19.4	10.4	78	107.2	444	606	.73	2.86
	60.6	23.1	10.9	78	103.6	438	565	.78	2.69
Average....	60.8	21.1	10.9	77	108.3	449	569	.79	2.72

[1] Average respiratory quotient for the day used in computing the heat-output.

[2] Carbon dioxide for the period and average respiratory quotient for the day used in computing the heat-output.

Table 10.—*Metabolism of W. K. during horizontal walking in experiments without food (Values per minute.)*—Continued.

Date.	Distance.	Average respiration-rate.	Average pulmonary ventilation (reduced).	Average pulse-rate.	No. of steps.	Carbon dioxide.	Oxygen.	Respiratory quotient.	Heat (computed).
1915	*meters.*		*liters.*			*c. c.*	*c. c.*		*cals.*
Mar. 17........	67.3	22.1	11.4	75	117.2	520	614	0.85	2.99
	67.4	24.8	11.5	73	116.8	502	564	.89	2.77
	67.8	22.3	11.4	77	116.2	487	572	.85	2.78
	67.5	22.8	11.3	....	114.6	493	565	.87	2.76
Average....	67.5	23.0	11.4	75	116.2	501	579	.87	2.83
Mar. 18........	62.5	21.2	11.1	77	108.0	492	569	.87	2.78
	58.4	20.7	10.2	74	100.0	443	537	.83	2.60
	60.8	22.6	10.5	77	106.2	448	532	.84	2.58
	58.8	19.7	9.9	78	104.2	432	526	.82	2.54
Average....	60.1	21.1	10.4	77	104.6	454	541	.84	2.62
Mar. 23........	64.3	20.5	12.0	83	111.6	456	(678)	(.67)	[1]2.82
	66.4	19.4	11.5	84	113.4	446	581	.77	2.77
	66.5	19.6	11.3	....	111.4	434	568	.76	2.70
Average....	65.7	19.8	11.6	84	112.1	445	575	.77	2 74
Mar. 25........	67.3	21.9	12.8	89	114.6	499	624	.80	3.00
	67.5	21.3	12.3	92	113.4	478	577	.83	2.79
	67.0	20.5	11.8	95	110.2	453	567	.80	2.72
Average....	67.3	21.2	12.3	92	112.7	477	589	.81	2.83
Mar. 29........	63.3	18.8	10.2	94	109.0	426	539	.79	2.58
	60.8	17.7	9.8	94	108.2	406	539	.75	2.55
	62.8	17.8	9.4	103	110.6	412	533	.77	2.54
Average....	62.3	18.1	9.8	97	109.3	415	537	.77	2.56
Mar. 31........	64.8	18.8	10.2	85	108.2	454	530	.86	2.58
	65.8	....	10.2	85	109.8	448	....	....	[1]2.59
	64.8	18.7	10.1	84	109.6	438	525	.84	2.55
	64.9	20.1	9.9	86	107.6	425	516	.83	2.50
Average....	65.1	19.2	10.1	85	108.8	441	524	.84	2.54
June 23........	58.2	21.7	10.3	81	108.0	411	472	.87	2.31
	57.1	20.5	10.1	72	106.0	385	473	.82	2.28
	56.0	20.7	9.9	72	105.4	383	455	.84	2.21
Average....	57.1	21.0	10.1	75	106.5	393	467	.84	2.26
Gen. av. (16 days)....	63.7	21.3	11.1	83	111.7	461	563	.82	2.72

---

[1] Carbon dioxide for the period and average respiratory quotient for the day used in computing the heat-output.

TABLE 11.—*Metabolism of E. D. B. during horizontal walking in experiments without food.* (*Values per minute.*)

Date.	Distance.	Average respiration-rate.	Average pulmonary ventilation (reduced).	Average pulse-rate.	No. of steps.	Carbon dioxide.	Oxygen.	Respiratory quotient.	Heat (computed).
1915.	*meters.*		*liters.*			*c. c.*	*c. c.*		*cals.*
Oct. 9	57.8	18.0	16.4	....	94.2	534	710	0.75	3.36
	56.4	19.6	16.2	....	91.8	516	659	.78	3.15
Average	57.1	18.8	16.3	....	93.0	525	685	.77	3.26
Oct. 11	56.3	19.5	17.6	....	89.0	535	610	.88	2.99
	53.7	20.0	15.4	....	96.8	484	625	.77	2.98
Average	55.0	19.8	16.5	....	92.9	510	618	.83	2.99
Oct. 13	55.8	17.0	15.1	....	87.0	....	611	[1].80	2.93
Oct. 14	55.3	19.5	16.7	....	88.4	462	585	.79	2.80
	54.2	20.6	16.9	....	88.2	458	600	.76	2.85
	54.1	20.2	16.8	....	87.8	467	612	.76	2.91
Average	54.5	20.1	16.8	....	88.1	462	599	.77	2.85
Oct. 15	55.4	18.6	16.4	....	88.9	470	575	.82	2.77
	54.3	17.9	15.8	....	88.1	458	593	.77	2.83
	53.6	15.5	14.8	....	89.4	469	609	.77	2.90
Average	54.4	17.3	15.7	....	88.8	466	592	.79	2.84
Oct. 16	65.2	16.3	16.5	....	98.0	539	600	.90	2.95
	64.9	19.7	18.0	....	97.4	529	618	.86	3.01
	65.0	17.6	16.6	....	97.6	511	633	.81	3.05
	64.9	19.1	17.3	....	97.4	517	624	.83	3.02
Average	65.0	18.2	17.1	....	97.6	524	619	.85	3.01
Oct. 18	63.4	12.2	11.9	....	96.6	528	582	.91	2.87
	64.5	15.2	12.9	....	97.2	538	615	.87	3.01
	64.4	16.0	13.0	....	94.4	535	600	.89	2.95
	64.8	17.0	13.3	....	97.4	539	614	.88	3.01
Average	64.3	15.1	12.8	....	96.4	535	603	.89	2.96
Oct. 19	64.6	15.9	12.7	....	97.0	522	591	.88	2.90
	64.1	17.7	13.1	....	96.4	513	658	.78	3.14
	63.9	18.3	13.0	....	96.4	499	617	.81	2.97
	64.5	18.7	13.2	....	96.2	515	669	.77	3.19
Average	64.3	17.7	13.0	....	96.5	512	634	.81	3.05
Oct. 20	64.6	16.7	13.6	....	97.4	542	610	.89	3.00
	64.4	17.8	13.7	....	97.0	537	647	.83	3.13
	64.7	19.6	14.1	....	97.8	532	644	.83	3.12
	64.5	20.3	13.9	....	97.8	523	645	.81	3.10
	64.7	20.9	14.1	....	98.2	530	642	.83	3.11
Average	64.6	19.1	13.9	....	97.6	533	638	.84	3.09

[1] Assumed.

TABLE 11.—*Metabolism of E. D. B. during horizontal walking in experiments without food. (Values per minute.)*—Continued.

Date.	Distance.	Average respiration rate.	Average pulmonary ventilation (reduced).	Average pulse-rate.	No. of steps.	Carbon dioxide.	Oxygen.	Respiratory quotient.	Heat (computed.)
1915.	*meters.*		*liters.*			*c. c.*	*c. c.*		*cals.*
Oct. 21.........	63.8	17.8	13.7	....	98.4	544	603	0.90	2.97
	63.6	17.6	13.3	....	97.6	524	636	.82	3.07
	63.7	20.5	14.3	....	97.0	532	636	.84	3.08
	63.8	20.4	13.7	....	96.8	529	645	.82	3.11
	64.3	21.4	13.5	....	96.7	517	638	.81	3.07
Average....	63.8	19.5	13.7	....	97.3	529	632	.84	3.07
Oct. 22.........	71.6	18.7	14.2	....	101.0	543	642	.85	3.12
	72.6	18.1	14.0	....	100.6	546	653	.84	3.17
	72.6	18.5	14.0	....	99.6	540	665	.81	3.20
	72.4	18.8	14.0	....	100.7	547	667	.82	3.22
Average....	72.3	18.5	14.1	....	100.5	544	657	.83	3.18
Oct. 23.........	71.6	15.4	13.5	....	101.8	564	667	.84	3.23
	72.4	18.3	14.3	....	101.0	555	674	.82	3.25
	72.2	18.6	13.9	....	100.6	542	662	.82	3.19
	72.6	19.4	14.2	....	100.8	544	675	.81	3.25
Average....	72.2	17.9	14.0	....	101.1	551	670	.82	3.23
Oct. 25.........	72.5	17.6	14.3	....	101.4	562	637	.88	3.12
	72.9	15.6	13.5	....	101.1	551	665	.83	3.22
	73.0	18.3	14.2	....	101.4	546	670	.81	3.22
	73.7	17.9	14.0	....	101.4	545	673	.81	3.24
	73.7	18.1	14.0	....	101.4	547	679	.81	3.27
Average....	73.2	17.5	14.0	....	101.4	550	665	.83	3.22
Oct. 26.........	72.5	16.4	13.1	....	103.0	516	657	.79	3.15
	72.2	17.0	13.0	....	101.8	510	671	.76	3.19
	73.5	19.3	14.0	....	102.4	529	680	.78	3.25
	72.9	18.4	13.5	....	102.6	519	667	.78	3.19
	73.2	18.7	13.7	....	102.2	521	677	.77	3.23
Average....	72.9	18.0	13.5	....	102.4	519	670	.78	3.20
Oct. 27.........	76.6	19.0	14.4	....	104.2	557	663	.84	3.22
	77.0	19.0	14.2	....	103.8	547	679	.81	3.27
	77.3	18.9	14.2	....	104.4	553	687	.80	3.30
	78.3	18.0	14.0	....	104.6	565	705	.80	3.38
	78.5	18.0	14.0	....	105.0	561	709	.79	3.40
	78.6	18.6	14.2	....	105.0	571	717	.80	3.44
Average....	77.7	18.6	14.2	....	104.5	559	693	.81	3.34
Oct. 28.........	77.1	17.5	14.4	....	106.6	594	654	.91	3.23
	77.8	17.7	14.2	....	106.6	576	677	.85	3.29
	77.8	19.3	14.6	....	105.8	568	688	.83	3.33
	78.1	18.8	14.4	....	106.4	573	695	.83	3.36
	78.2	17.8	14.1	....	107.2	566	682	.83	3.30
Average....	77.8	18.2	14.3	....	106.5	575	679	.85	3.30

TABLE 11.—*Metabolism of E. D. B. during horizontal walking in experiments without food. (Values per minute.)*—Continued.

Date.	Distance.	Average respiration rate.	Average pulmonary ventilation (reduced).	Average pulse-rate.	No. of steps.	Carbon dioxide.	Oxygen.	Respiratory quotient.	Heat (computed).
1915.	*meters.*		*liters.*			*c. c.*	*c. c.*		*cals.*
Oct. 29	77.1	16.8	13.9	68	104.4	592	689	0.86	3.36
	78.1	19.5	14.5	77	106.1	570	688	.83	3.33
	78.3	19.3	14.5	88	104.4	577	704	.82	3.40
	78.5	20.9	15.4	93	104.4	597	723	.83	3.50
Average	78.0	19.1	14.6	82	104.8	584	701	.83	3.39
Oct. 30	45.2	16.7	11.1	....	80.0	429	496	.86	2.42
	43.5	18.2	11.4	....	81.0	419	474	.88	2.32
	43.1	18.5	11.1	....	79.8	401	484	.83	2.34
Average	43.9	17.8	11.2	....	80.3	416	485	.86	2.36
Nov. 1	44.9	17.4	11.4	....	79.2	434	471	.92	2.33
	44.5	19.2	11.5	....	80.0	411	473	.87	2.31
	43.5	18.0	11.2	....	79.8	406	478	.85	2.32
Average	44.3	18.2	11.4	....	79.7	417	474	.88	2.32
Nov. 2	43.9	18.1	11.1	....	80.8	420	470	.89	2.31
	43.4	19.2	11.3	....	79.4	412	483	.85	2.35
	42.3	18.3	10.9	....	79.4	403	473	.85	2.30
Average	43.2	18.5	11.1	....	79.9	412	475	.87	2.32
Nov. 3	45.4	18.6	11.1	....	80.8	415	461	.90	2.27
	44.7	18.6	11.0	....	80.0	398	469	.85	2.28
	43.4	19.1	10.9	....	95.2	403	455	.89	2.23
Average	44.5	18.8	11.0	....	85.3	405	462	.88	2.26
Nov. 4	53.5	20.3	12.2	....	86.4	435	497	.87	2.43
	53.2	21.2	12.3	....	86.4	431	502	.86	2.45
	53.9	21.5	12.8	....	86.6	438	526	.83	2.54
Average	53.5	21.0	12.4	....	86.5	435	508	.86	2.48
Nov. 5	46.9	19.3	11.4	....	82.2	422	473	.89	2.32
	46.2	20.2	11.2	63	81.8	400	478	.84	2.32
	45.6	20.0	11.5	68	81.6	398	479	.83	2.32
Average	46.2	19.8	11.4	66	81.9	407	477	.85	2.32
Nov. 6	46.8	18.8	11.1	63	82.0	407	457	.89	2.24
	45.8	19.1	11.0	67	80.8	405	458	.89	2.25
	45.0	18.9	10.9	71	79.6	402	462	.87	2.26
Average	45.9	18.9	11.0	67	80.8	405	459	.88	2.25
Nov. 8	55.2	17.2	11.9	....	89.0	484	510	.95	2.54
	56.1	19.1	12.3	....	88.2	480	523	.92	2.59
	57.0	19.8	12.3	....	89.8	474	525	.90	2.59
Average	56.1	18.7	12.2	....	89.0	479	519	.92	2.57

TABLE 11.—*Metabolism of E. D. B. during horizontal walking in experiments without food. (Values per minute.)*—Continued.

Date.	Distance.	Average respiration-rate.	Average pulmonary ventilation (reduced).	Average pulse-rate.	No. of steps.	Carbon dioxide.	Oxygen.	Respiratory quotient.	Heat (computed).
1915.	*meters.*		*liters.*			*c. c.*	*c. c.*		*cals.*
Nov. 9.........	54.9	20.1	12.3	....	88.8	460	486	0.95	2.42
	54.5	21.6	12.5	....	87.6	448	(520)	(.86)	[1]2.41
	54.6	21.0	12.3	....	87.6	452	498	.91	2.46
Average....	54.7	20.9	12.4	....	88.0	453	492	.92	2.43
Nov. 10........	48.4	19.8	11.6	67	84.2	418	460	.91	2.27
	47.8	21.0	11.8	....	85.2	411	476	.86	2.32
	47.1	21.1	12.0	....	84.8	417	489	.85	2.38
Average....	47.8	20.6	11.8	67	84.7	415	475	.87	2.32
Nov. 11........	67.1	20.6	13.6	73	99.0	524	560	.94	2.78
	68.2	21.9	18.3	....	98.8	524	608	.86	2.96
	68.4	20.1	13.7	....	99.2	516	603	.85	2.93
Average....	67.9	20.9	15.2	73	99.0	521	590	.88	2.89
Nov. 12........	66.0	19.8	13.6	81	99.2	528	573	.92	2.84
	67.7	20.3	14.1	....	99.4	523	593	.88	2.91
	67.6	21.4	14.3	....	98.8	530	592	.90	2.92
Average....	67.1	20.5	14.0	81	99.1	527	586	.90	2.89
Nov. 13........	76.1	19.6	14.5	78	104.2	584	608	.96	3.04
	76.9	20.8	15.0	84	103.2	583	657	.89	3.23
	77.0	23.9	15.2	....	104.4	560	635	.88	3.11
Average....	76.7	21.4	14.9	81	103.9	576	633	.91	3.12
Nov. 15........	76.3	19.6	14.4	87	103.0	606	631	.96	3.15
	77.1	22.2	14.9	....	104.6	595	649	.92	3.21
	77.5	21.3	14.8	....	104.4	581	645	.90	3.18
Average....	77.0	21.0	14.7	87	104.0	594	642	.93	3.18
Nov. 16........	76.4	20.3	14.4	76	102.8	563	654	.86	3.19
	77.0	21.3	14.3	84	104.2	538	657	.82	3.17
	77.4	22.9	14.7	86	104.1	530	658	.81	3.17
Average....	76.9	21.5	14.5	82	103.7	544	656	.83	3.17
Nov. 17........	46.2	20.4	12.2	81	79.0	404	470	.86	2.29
	45.4	20.3	11.8	....	79.0	394	471	.84	2.28
	45.6	21.2	12.3	....	79.0	400	473	.85	2.30
Average....	45.7	20.6	12.1	81	79.0	399	471	.85	2.29
Nov. 18........	55.7	19.9	12.3	....	90.8	424	507	.84	2.46
	54.9	21.0	12.5	....	87.4	416	491	.85	2.39
	54.6	21.7	12.6	....	87.4	423	511	.83	2.47
	54.9	21.7	13.0	....	88.0	428	516	.83	2.50
	54.7	21.8	13.0	....	87.8	436	518	.84	2.51
Average....	55.0	21.2	12.7	....	88.3	425	509	.84	2.47

---

[1] Computed from the carbon dioxide for the period and the respiratory quotient for the day.

Table 11.—*Metabolism of E. D. B. during horizontal walking in experiments without food. (Values per minute.)*—Continued.

Date.	Distance.	Average respiration-rate.	Average pulmonary ventilation (reduced).	Average pulse-rate.	No. of steps.	Carbon dioxide.	Oxygen.	Respiratory quotient.	Heat (computed.)
1915.	*meters.*		*liters.*			*c. c.*	*c. c.*		*cals.*
Nov. 19........	76.5	19.7	14.2	....	104.8	532	630	0.85	3.06
	77.7	22.9	15.4	....	104.3	549	672	.82	3.24
	77.9	22.6	14.7	....	103.0	529	665	.80	3.19
	78.4	23.2	14.6	....	104.6	535	670	.80	3.22
	78.9	23.8	14.9	....	104.0	546	676	.81	3.25
Average....	77.9	22.4	14.8	....	104.1	538	663	.82	3.20
Nov. 22........	48.0	20.0	12.0	....	82.2	422	484	.87	2.37
	47.3	20.1	11.8	....	80.2	416	486	.86	2.37
	46.8	19.6	11.5	....	79.8	406	478	.85	2.32
Average....	47.4	19.9	11.8	....	80.7	415	483	.86	2.35
Nov. 23........	55.5	20.7	12.2	66	89.2	445	491	.90	2.42
	53.9	21.2	12.7	....	86.2	432	491	.88	2.41
	54.9	21.5	12.5	....	87.8	440	495	.89	2.43
Average....	54.8	21.1	12.5	66	87.7	439	492	.89	2.42
Nov. 24........	57.7	21.6	13.2	....	90.4	460	490	.94	2.44
	57.6	21.8	13.3	....	89.6	447	500	.89	2.46
	57.1	21.1	13.4	....	90.0	445	502	.89	2.47
Average....	57.5	21.5	13.3	....	90.0	451	497	.91	2.45
Nov. 26........	65.3	20.2	11.7	....	98.2	519	546	.95	2.72
	66.2	19.8	11.6	....	99.2	527	559	.94	2.78
	66.2	22.8	12.4	....	97.6	515	564	.91	2.78
Average....	65.9	20.9	11.9	....	98.3	520	556	.93	2.76
Dec. 1.........	74.9	19.5	13.8	82	105.0	599	627	.96	3.13
	76.4	21.0	15.0	87	104.8	599	657	.91	3.24
	77.3	21.6	15.0	87	106.2	575	647	.89	3.18
Average....	76.2	20.7	14.6	85	105.3	591	644	.92	3.19
Dec. 2.........	71.3	20.6	13.5	79	101.8	549	579	.95	2.89
	71.8	21.4	14.1	81	101.8	539	596	.90	2.93
	71.8	22.2	13.7	82	101.8	522	585	.89	2.87
Average....	71.6	21.4	13.8	81	101.8	537	587	.91	2.90
Dec. 3.........	70.5	21.3	13.5	82	103.2	550	597	.92	2.95
	71.2	22.3	13.5	86	101.1	532	605	.88	2.96
	72.1	23.1	14.3	....	101.3	526	609	.86	2.97
Average....	71.3	22.2	13.8	84	101.9	536	604	.89	2.96
Dec. 4.........	47.5	19.3	11.1	....	79.4	415	449	.93	2.23
	46.6	18.7	11.0	....	79.2	395	448	.88	2.20
	45.9	19.2	12.1	....	78.4	394	459	.86	2.24
Average....	46.7	19.1	11.4	....	79.0	401	452	.89	2.21

TABLE 11.—*Metabolism of E. D. B. during horizontal walking in experiments without food. (Values per minute.)*—Continued.

Date.	Distance.	Average respiration-rate.	Average pulmonary ventilation (reduced).	Average pulse-rate.	No. of steps.	Carbon dioxide.	Oxygen.	Respiratory quotient.	Heat (computed).
1915.	*meters.*		*liters.*			*c. c.*	*c. c.*		*cals.*
Dec. 6.........	45.2	18.0	10.5	63	78.8	402	440	0.91	2.17
	45.1	18.7	10.2	67	78.4	383	450	.85	2.19
	44.7	19.5	10.6	67	78.2	384	441	.87	2.16
Average....	45.0	18.7	10.4	66	78.5	390	444	.88	2.18
Dec. 7.........	43.8	19.1	10.8	75	78.8	413	453	.91	2.24
	43.1	19.9	11.1	79	77.2	410	445	.92	2.20
	50.6	20.8	11.8	81	75.2	424	484	.88	2.37
Average....	45.8	19.9	11.2	78	77.1	416	461	.90	2.27
Dec. 13.........	66.8	19.0	12.6	71	98.6	465	540	.86	2.63
	66.6	20.0	13.1	78	97.8	476	582	.82	2.81
	66.7	20.6	13.2	82	96.4	457	556	.82	2.68
Average....	66.7	19.9	13.0	77	97.6	466	559	.83	2.70
1916. Jan. 31.........	62.0	19.2	14.8	92	99.0	553	659	.84	3.20
	63.5	20.7	14.6	....	97.0	533	672	.79	3.22
	63.4	21.5	14.2	105	94.4	534	688	.78	3.29
	63.9	21.4	14.2	....	93.4	532	673	.79	3.22
Average....	63.2	20.7	14.5	99	96.0	538	673	.80	3.23
Feb. 1.........	62.9	20.3	14.9	94	93.4	572	650	.88	3.19
	63.2	21.6	13.9	97	94.4	518	642	.81	3.09
	64.3	22.5	13.6	97	94.8	492	614	.80	2.95
	63.9	21.5	14.2	99	94.0	521	646	.81	3.11
Average....	63.6	21.5	14.2	97	94.2	526	638	.82	3.08
Mar. 20.........	59.5	21.2	18.1	....	....	514	604	.85	2.94
	60.7	22.8	18.4	....	....	509	581	.88	2.85
Average....	60.1	22.0	18.3	....	....	512	593	.86	2.89
Mar. 22.........	74.8	21.0	15.3	80	....	566	689	.82	3.32
	76.9	22.1	15.4	88	....	581	703	.83	3.40
Average....	75.9	21.6	15.4	84	....	574	696	.82	3.36
Mar. 29.........	57.6	22.2	13.5	86	....	477	604	.79	2.89
	55.5	21.9	13.8	85	....	479	593	.81	2.85
Average....	56.6	22.1	13.7	86	....	478	599	.80	2.88
Mar. 30.........	68.5	18.0	15.2	83	....	584	681	.86	3.32
	63.6	23.3	15.8	82	....	532	622	.85	3.02
Average....	66.1	20.7	15.5	83	....	558	651	.86	3.17
Mar. 31.........	55.2	21.7	15.4	68	....	512	539	.95	2.69
	52.9	21.2	12.8	77	....	507	552	.92	2.73
Average....	54.1	21.5	14.1	73	....	510	546	.93	2.71

TABLE 11.—*Metabolism of E. D. B. during horizontal walking in experiments without food* (*Values per minute.*)—Continued.

Date.	Distance.	Average respiration-rate.	Average pulmonary ventilation (reduced).	Average pulse-rate.	No. of steps.	Carbon dioxide.	Oxygen.	Respiratory quotient.	Heat (computed).
1916.	*meters.*		*liters.*			*c. c.*	*c. c.*		*cals.*
Apr. 1.........	53.4	21.7	13.5	71	....	472	547	0.86	2.67
	51.7	21.1	12.9	....	....	451	540	.83	2.61
	50.4	21.3	12.3	80	....	445	536	.83	2.59
Average....	51.8	21.4	12.9	76	....	456	541	.84	2.62
Apr. 3.........	35.1	19.3	11.7	68	....	401	443	.90	2.18
	35.7	19.8	11.7	70	....	406	464	.87	2.27
	36.7	18.8	11.0	75	....	391	464	.84	2.25
Average....	35.8	19.3	11.5	71	....	399	457	.87	2.23
Apr. 4.........	35.9	19.4	11.6	69	....	395	475	.83	2.30
	37.0	19.0	11.0	74	....	385	466	.83	2.25
	37.0	18.9	10.8	73	....	378	488	.78	2.33
Average....	36.6	19.1	11.1	72	....	386	476	.81	2.29
Apr. 5.........	77.4	21.4	19.7	87	....	598	732	.82	3.53
	76.5	23.1	15.5	92	....	580	708	.82	3.42
	79.3	22.7	15.8	96	....	600	726	.83	3.51
Average....	77.7	22.4	17.0	92	....	593	722	.82	3.48
Apr. 10.........	78.7	22.2	17.9	....	....	679	722	.94	3.59
	77.1	24.0	19.4	88	....	654	722	.91	3.56
Average....	77.9	23.1	18.7	88	....	667	722	.92	3.57
Apr. 11.........	95.9	21.2	20.1	91	....	799	914	.87	4.47
	92.0	24.3	19.7	99	....	743	845	.88	4.14
	89.0	24.9	18.9	104	....	707	845	.84	4.10
Average....	92.3	23.5	19.6	98	....	750	868	.86	4.24
Apr. 12.........	89.2	22.9	18.8	86	....	731	901	.81	4.34
	89.0	25.1	18.6	92	....	705	868	.81	4.18
	86.6	23.3	17.6	....	....	677	840	.81	4.04
Average....	88.3	23.8	18.3	89	....	704	870	.81	4.19
Apr. 13.........	99.7	24.4	20.9	95	....	819	928	.88	4.55
	97.7	23.5	20.2	102	....	812	942	.86	4.59
	94.9	26.2	19.7	103	....	762	877	.87	4.29
Average....	97.4	24.7	20.3	100	....	798	916	.87	4.48
Gen. av. (61 days)	62.2	20.3	14.0	81	93.0	508	595	.85	2.89

Table 11a.—*Average body-temperature and blood-pressure of E. D. B. during horizontal walking experiments without food. (Values per minute.)*

Date.	Average body-temperature.	Blood-pressure.
1916.	*°C.*	*mm.*
Jan. 31	37.03	....
	37.20	....
	37.34	....
	37.42	....
Average	37.25	....
Feb. 1	37.05	....
	37.21	....
	37.28	....
	37.34	....
Average	37.22	....
Mar. 20	36.59	122
	36.78	123
Average	36.69	123
Mar. 22	36.90	122
	37.00	118
Average	36.95	120
Mar. 29	36.91	124
	37.00	125
Average	36.96	125
Mar. 30	37.13	119
	37.17	117
Average	37.15	118
Mar. 31	36.86	124
	37.14	127
Average	37.00	126
Apr. 1	36.80	124
	37.02	125
	37.17	123
Average	37.00	124
1916.	*°C.*	*mm.*
Apr. 3	36.86	124
	37.12	123
	37.31	121
Average	37.10	123
Apr. 4	36.55	117
	36.73	118
	36.84	118
Average	36.71	118
Apr. 5	37.06	123
	37.23	127
	37.38	125
Average	37.22	125
Apr. 10	36.95	129
	37.09	129
Average	37.02	129
Apr. 11	36.94	130
	37.29	129
	37.43	129
Average	37.22	129
Apr. 12	36.95	130
	37.28	129
	37.33	130
Average	37.19	130
Apr. 13	37.09	131
	37.46	131
	37.62	131
Average	37.39	131
Gen. av.	[1]37.07	[2]125

[1] For 15 days.

[2] For 13 days.

TABLE 12.—*Metabolism of J. H. G., E. L. F., and H. M. S. during horizontal walking in experiments without food. (Values per minute.)*

Date.	Distance.	Average respiration-rate.	Av'age pulmonary ventilation (reduced).	Average pulse-rate.	No. of steps.	Carbon dioxide.	Oxygen.	Respiratory quotient.	Heat (computed).
J. H. G.									
1916.	*meters.*		*liters.*			*c. c.*	*c. c.*		*cals.*
Jan. 18.........	55.3	18.2	13.6	96	83.8	578	743	0.78	3.55
	55.2	18.4	13.2	98	90.6	555	724	.77	3.45
	54.5	17.5	12.6	98	90.0	541	713	.76	3.39
Average....	55.0	18.0	13.1	97	88.1	558	727	.77	3.46
Jan. 19.........	55.3	17.7	13.7	89	88.9	553	689	.81	3.31
	55.1	19.7	17.3	....	105.2	538	721	.75	3.42
	53.8	20.4	17.9	....	108.8	521	699	.75	3.31
Average....	54.7	19.3	16.3	89	101.0	537	703	.76	3.34
Jan. 20.........	55.9	18.6	17.6	93	89.7	576	686	.84	3.33
	55.6	19.6	17.6	94	96.2	545	698	.78	3.33
	53.5	20.2	17.8	97	105.4	550	678	.81	3.26
Average....	55.0	19.5	17.7	95	97.1	557	687	.81	3.31
Gen. av. (3 days)	54.9	18.9	15.7	94	95.4	551	706	.78	3.37
E. L. F.									
Jan. 21.........	52.5	16.0	18.0	87	90.6	638	804	.80	3.85
	52.3	18.1	13.9	86	90.4	549	711	.77	3.39
	52.5	19.4	14.2	90	89.8	541	715	.76	3.40
Average....	52.4	17.8	15.4	88	90.3	576	743	.78	3.55
Jan. 22.........	53.6	7.9	14.4	87	96.6	618	688	.90	3.39
	52.5	6.2	13.1	92	93.2	580	703	.83	3.40
	52.3	6.4	13.1	93	....	589	683	.86	3.33
Average....	52.8	6.8	13.5	91	94.9	596	691	.86	3.37
Jan. 24.........	49.6	5.4	13.3	97	95.9	552	681	.81	3.28
	49.2	5.4	13.7	101	100.8	541	675	.80	3.24
	48.4	5.4	13.8	101	90.4	538	666	.81	3.21
Average....	49.1	5.4	13.6	100	95.7	544	674	.81	3.24
Gen. av. (3 days)	51.4	10.0	14.2	93	93.6	572	703	.81	3.38
H. M. S.									
Jan. 25.........	44.6	16.6	12.4	....	79.2	476	626	.76	2.97
	42.2	17.9	11.9	92	76.2	449	584	.77	2.78
	41.6	18.1	11.9	93	76.0	429	594	.72	2.79
Average....	42.8	17.5	12.1	93	77.1	451	601	.75	2.85
Jan. 26.........	53.5	15.4	12.7	....	90.4	525	665	.79	3.18
	52.7	17.3	12.7	....	77.2	495	647	.77	3.07
	52.3	19.3	12.8	88	83.2	479	644	.74	3.04
Average....	52.8	17.3	12.7	88	83.6	500	652	.77	3.11
Gen. av. (2 days)	47.8	17.4	12.4	91	80.4	476	627	.76	2.98

Table 13.—*Metabolism of A. J. O., and H. R. R. during grade walking in experiments without food. (Values per minute.)*

Date.	Grade.	Distance.	Average respiration-rate.	Average pulmonary ventilation (reduced).	Average pulse-rate.	No. of steps.	Carbon dioxide.	Oxygen.	Respiratory quotient.	Heat (computed).
A. J. O.										
1915.	*p. ct.*	*meters.*		*liters.*			*c. c.*	*c. c.*		*cals.*
Mar. 2......	......	61.1	24.5	17.6	......	94.4	749	871	0.86	4.25
	......	68.1	25.2	18.0	......	102.6	822	955	.86	4.66
Average..	3.6	64.6	24.9	17.8	......	98.5	786	913	.86	4.45
H. R. R.										
1915.										
Mar. 27.....	......	66.4	24.5	29.5	147	105.6	1,445	1,672	.87	8.17
	......	66.4	26.8	29.5	......	105.4	1,398	1,687	.83	8.16
	......	66.8	27.4	30.3	......	105.4	1,427	1,730	.83	8.35
	......	66.6	30.3	31.8	......	104.8	1,458	1,727	.85	8.40
Average..	10.6	66.6	27.3	30.3	147	105.3	1,432	1,704	.84	8.26
Apr. 3.......	......	61.7	24.5	27.7	143	97.4	1,309	1,532	.86	7.47
	......	61.9	25.0	28.1	......	98.8	1,308	1,553	.84	7.53
	......	61.8	26.1	28.7	......	99.6	1,291	1,578	.82	7.61
	......	62.2	27.4	30.5	......	102.6	1,339	1,634	.82	7.88
Average..	10.2	61.9	25.8	28.7	143	99.6	1,312	1,574	.83	7.62
Apr. 24......	......	63.8	23.3	25.9	130	100.6	1,255	1,502	.84	7.28
	......	64.2	23.7	26.1	143	100.6	1,241	1,553	.80	7.46
	......	64.1	24.0	26.3	144	102.0	1,239	1,532	.81	7.37
Average..	10.5	64.0	23.7	26.1	139	101.1	1,245	1,529	.81	7.36
May 1.......	......	71.8	23.4	29.8	132	108.2	1,466	1,667	.88	8.17
	......	72.5	25.5	30.8	136	108.8	1,465	1,705	.86	8.31
	......	73.1	26.5	31.8	142	108.6	1,484	1,741	.86	8.49
	......	73.2	27.1	32.6	151	109.2	1,560	1,830	.85	8.90
	......	73.0	27.9	33.3	163	107.8	1,547	1,834	.85	8.92
	......	72.9	30.9	31.4	166	106.8	1,515	1,820	.83	8.81
Average..	10.5	72.8	26.9	31.6	148	108.2	1,506	1,766	.85	8.59
May 8.......	......	75.9	22.3	30.1	......	112.4	1,525	1,742	.88	8.54
	......	76.1	23.9	31.1	......	112.0	1,534	1,777	.87	8.68
	......	76.5	24.3	31.4	......	111.8	1,564	1,820	.86	8.87
	......	76.7	24.7	32.5	......	112.0	1,589	1,855	.86	9.04
	......	77.0	25.7	32.9	......	111.4	1,548	1,911	.81	9.20
	......	77.0	26.6	34.1	......	111.2	1,593	1,913	.84	9.28
Average..	10.5	76.5	24.6	32.0	......	111.8	1,559	1,836	.85	8.93
May 22.....	......	66.5	26.2	36.8	134	104.6	1,783	2,014	.89	9.89
	......	66.3	27.2	36.9	148	106.6	1,735	2,028	.86	9.89
	......	65.7	28.5	37.5	154	106.6	1,741	2,042	.85	9.93
	......	66.3	29.0	39.0	164	108.4	1,787	2,077	.86	10.13
Average..	15.3	66.2	27.7	37.6	150	106.6	1,762	2,040	.86	9.95

Table 14.—*Metabolism of T. H. H. during grade walking in experiments without food. (Values per minute.)*

Date.	Grade.	Distance.	Average respiration-rate.	Average pulmonary ventilation (reduced).	Average pulse-rate.	No. of steps.	Carbon dioxide.	Oxygen.	Respiratory quotient.	Heat (computed).
1915.	*p. ct.*	*meters.*		*liters.*			*c. c.*	*c. c.*		*cals.*
Mar. 24.....	......	63.4	15.9	16.7	114	97.4	1,028	1,136	0.91	5.61
	......	62.3	16.5	17.3	120	98.0	1,017	1,173	.87	5.73
	......	62.1	17.0	16.7	121	98.0	974	1,153	.85	5.61
Average..	10.3	62.6	16.5	16.9	118	97.8	1,006	1,154	.87	5.64
Mar. 26.....	......	63.4	16.6	17.3	113	96.2	1,065	1,174	.91	5.79
	......	64.3	16.7	17.5	117	100.6	1,067	1,196	.89	5.87
	......	64.1	17.3	18.0	120	100.2	1,064	1,219	.88	5.97
	......	63.9	17.8	18.0	126	96.6	1,046	1,251	.84	6.07
Average..	10.3	63.9	17.1	17.7	119	98.4	1,061	1,210	.88	5.93
Mar. 30.....	......	62.1	18.4	18.8	......	101.6	1,057	1,178	.90	5.80
	......	61.0	19.2	18.8	117	99.8	1,011	1,166	.87	5.70
	......	61.3	19.4	19.1	......	101.4	1,014	1,222	.83	5.91
Average..	10.2	61.5	19.0	18.9	117	100.9	1,027	1,189	.86	5.80
Apr. 5.......	......	62.3	17.9	18.4	126	103.4	1,056	1,241	.85	6.03
	......	63.2	19.0	18.8	132	104.2	1,050	1,309	.80	6.28
	......	63.7	18.8	18.9	......	102.8	1,039	1,339	.78	6.40
Average..	10.4	63.1	18.6	18.7	129	103.5	1,048	1,296	.81	6.24
Apr. 6.......	......	58.4	17.6	17.5	118	99.0	1,019	1,135	.90	5.59
	......	59.3	19.0	18.1	123	100.8	1,021	1,144	.89	5.62
	......	60.2	19.0	17.9	125	100.6	1,012	1,167	.87	5.70
	......	59.4	19.0	18.1	129	101.6	968	1,268	.77	6.04
	......	60.1	20.0	17.9	136	103.2	1,006	1,231	.82	5.94
	......	60.4	21.0	18.3	147	103.6	1,009	1,275	.79	6.11
Average..	10.4	59.6	19.3	18.0	130	101.5	1,006	1,203	.84	5.83
Apr. 7.......	......	56.1	18.7	17.4	121	98.6	957	1,118	.86	5.45
	......	56.4	18.8	17.7	118	100.4	953	1,130	.85	5.50
	......	56.3	18.1	17.1	124	99.8	932	1,134	.82	5.47
	......	56.6	18.4	17.0	133	100.6	941	1,152	.82	5.56
	......	56.5	18.6	17.2	139	101.0	931	1,160	.80	5.57
	......	57.2	17.9	17.2	146	103.6	968	1,207	.80	5.79
	......	57.6	18.6	17.6	......	103.6	979	1,206	.81	5.80
Average..	10.4	56.7	18.4	17.3	130	101.1	952	1,158	.82	5.59
Apr. 8.......	......	67.8	18.6	19.3	......	105.4	1,115	1,300	.86	6.34
	......	68.0	19.4	19.7	......	105.6	1,089	1,277	.86	6.23
	......	67.5	19.9	19.7	......	104.8	1,088	1,308	.83	6.33
	......	67.9	20.8	20.3	......	103.2	1,100	1,322	.83	6.40
	......	68.6	21.2	20.6	......	103.4	1,090	1,347	.81	6.48
	......	69.0	20.5	20.4	......	104.4	1,079	1,374	.79	6.58
Average..	10.4	68.1	20.1	20.0	......	104.5	1,094	1,321	.83	6.39
Apr. 15......	......	63.9	14.2	16.7	100	101.4	972	1,178	.83	5.70
	......	65.0	15.5	17.0	102	100.0	1,011	1,204	.84	5.84
	......	64.8	17.0	16.9	104	99.2	992	1,196	.83	5.79
	......	65.0	17.7	16.6	107	100.6	981	1,204	.82	5.81
	......	65.4	18.1	17.5	116	101.6	985	1,232	.80	5.91
	......	65.9	18.8	17.7	119	101.0	998	1,245	.80	5.98
Average..	10.3	65.0	16.9	17.1	108	100.6	990	1,210	.82	5.84

TABLE 15.—*Metabolism of W. K. during grade walking in experiments without food. (Values per minute.)*

Date.	Grade.	Distance.	Average respiration-rate.	Average pulmonary ventilation (reduced).	Average pulse-rate.	No. of steps.	Carbon dioxide.	Oxygen.	Respiratory quotient.	Heat (computed).
1915.	*p. ct.*	*meters.*		*liters.*			*c. c.*	*c. c.*		*cals.*
Mar. 4......	......	69.5	24.0	16.9	......	114.8	733	810	0.91	4.00
	......	68.9	24.8	15.7	......	113.5	691	770	.90	3.79
	......	68.9	25.5	16.3	......	114.0	701	782	.90	3.85
Average..	3.6	69.1	24.8	16.3	......	114.1	708	787	.90	3.88
Mar. 5......	......	67.5	22.1	11.0	......	116.3	666	758	.88	3.71
	......	68.3	23.0	13.5	......	116.0	643	763	.85	3.71
	......	68.3	23.1	13.5	......	116.0	638	767	.83	3.71
	......	68.4	22.8	13.1	......	114.2	625	775	.81	3.73
Average..	3.6	68.1	22.8	12.8	......	115.6	643	766	.84	3.72
Mar. 8......	......	68.9	22.7	14.9	......	118.2	678	790	.86	3.85
	......	69.6	27.8	16.0	......	118.6	671	848	.79	4.06
	......	70.1	28.3	16.6	......	117.6	688	812	.85	3.95
Average..	3.9	69.5	26.3	15.8	......	118.1	679	817	.83	3.95
Mar. 9......	......	70.0	22.6	14.0	......	117.8	655	803	.82	3.87
	......	70.5	27.9	14.8	......	117.6	652	802	.81	3.86
Average..	3.9	70.3	25.3	14.4	......	117.7	654	803	.81	3.86
Mar. 23.....	......	63.2	23.7	20.2	110	108.2	872	1,004	.87	4.91
	......	66.6	25.0	20.3	114	108.4	857	......	......	[1]4.81
	......	63.2	26.1	20.2	117	109.4	871	1,024	.85	4.98
	......	63.5	26.5	20.5	119	107.6	910	1,032	.88	5.06
Average..	9.2	64.1	25.3	20.3	115	108.4	878	1,020	.86	4.97
Mar. 25.....	......	60.9	23.6	19.5	120	104.6	861	1,028	.84	4.99
	......	60.8	24.8	19.8	120	103.6	855	1,050	.82	5.07
	......	60.8	25.0	20.0	128	100.8	856	1,042	.82	5.03
Average..	10.7	60.8	24.5	19.8	123	103.0	857	1,040	.82	5.02
Mar. 31.....	......	58.3	24.7	18.3	113	104.0	837	978	.86	4.77
	......	58.3	25.4	18.2	123	105.4	843	987	.86	4.81
	......	58.2	25.1	18.2	125	103.4	835	995	.84	4.83
	......	58.9	26.1	18.4	129	104.4	929	1,007	.93	4.99
Average..	10.3	58.4	25.3	18.3	123	104.3	861	992	.87	4.85
Apr. 2.......	......	57.6	24.6	20.0	108	98.9	860	964	.89	4.74
	......	57.9	24.4	19.8	108	99.6	817	981	.83	4.75
	......	57.9	24.9	19.6	......	100.0	812	1,105	.74	5.22
	......	58.8	25.0	20.1	112	100.6	846	988	.86	4.82
	......	58.7	25.1	17.9	112	101.6	825	1,098	.75	5.20
	......	58.6	24.5	17.8	116	99.8	802	1,005	.80	4.83
	......	57.7	25.1	19.2	115	99.0	816	992	.83	4.80
Average..	10.3	58.2	24.8	19.2	112	99.9	825	1,019	.81	4.90

---

[1] Computed from the carbon dioxide for the period and the average of the respiratory quotients for the day.

TABLE 15.—*Metabolism of W. K. during grade walking in experiments without food. (Values per minute.)*—Continued.

Date.	Grade.	Distance.	Average respiration-rate.	Average pulmonary ventilation (reduced).	Average pulse-rate.	No. of steps.	Carbon dioxide.	Oxygen.	Respiratory quotient.	Heat (computed).
1915.	*p. ct.*	*meters.*		*liters.*			*c. c.*	*c. c.*		*cals.*
Apr. 12......	......	59.5	24.4	18.5	118	107.6	833	1,025	0.82	4.95
	......	59.8	24.3	19.7	......	107.4	846	1,036	.82	5.00
	......	59.1	25.3	18.0	......	106.0	798	1,014	.79	4.86
	......	59.1	25.5	19.6	......	103.6	809	1,044	.78	4.99
	......	57.9	24.5	17.2	126	101.8	815	1,029	.79	4.93
	......	58.1	24.3	17.5	125	104.8	801	1,093	.74	5.15
	......	58.0	23.9	18.9	130	107.2	806	1,022	.79	4.89
Average..	10.5	58.8	24.6	18.5	125	105.5	815	1,038	.79	4.97
Apr. 13......	......	58.6	24.8	18.5	......	106.8	801	1,076	.75	5.10
	......	58.2	24.4	18.0	......	105.2	814	982	.83	4.75
	......	58.3	24.9	17.5	......	103.6	820	981	.84	4.76
Average..	10.5	58.4	24.7	18.0	......	105.2	812	1,013	.80	4.86
Apr. 14......	......	63.9	26.3	21.8	......	112.0	931	1,041	.90	5.13
	......	64.5	26.5	21.4	......	111.2	921	1.069	.86	5.21
	......	64.5	27.1	21.2	......	110.0	902	1,051	.86	5.12
	......	64.9	26.9	19.6	......	108.2	921	1,112	.83	5.38
	......	65.0	26.5	19.6	......	106.6	900	1,073	.84	5.20
Average..	10.5	64.6	26.7	20.7	......	109.6	915	1,069	.86	5.21
Apr. 16......	......	64.1	26.2	18.7	112	106.4	904	1,063	.85	5.17
	......	64.1	26.1	19.1	120	105.8	893	1,016	.88	4.98
	......	64.4	26.8	19.2	125	107.4	871	1,150	.76	5.46
	......	64.1	26.7	18.7	130	108.4	871	1,045	.84	5.06
	......	64.4	26.9	18.9	133	106.8	869	1,047	.83	5.07
	......	64.9	27.0	18.7	137	108.0	858	1,077	.80	5.17
	......	65.2	27.5	19.2	139	108.2	880	1,076	.82	5.19
Average..	10.3	64.5	26.7	18.9	128	107.3	878	1,068	.82	5.15
Apr. 20......	......	69.2	26.2	19.9	114	110.8	951	1,207	.79	5.78
	......	69.6	26.8	19.6	118	111.0	943	1,217	.78	5.81
	......	......	......	......	123	......	......	......	......	......
	......	69.1	27.2	18.6	125	108.9	884	(1,374)	(.65)	[1]5.41
	......	69.3	27.4	19.4	125	110.8	958	1,121	.86	5.46
	......	69.2	27.5	18.8	127	110.8	879	(1,349)	(.65)	5.38
	......	69.7	27.4	18.6	131	112.6	906	1,277	.71	5.99
Average..	10.5	69.4	27.1	19.1	123	110.8	920	1,206	.76	5.73
Apr. 21......	......	70.0	27.1	22.6	106	111.2	946	1,158	.82	5.59
	......	70.0	27.0	21.8	111	111.4	931	1,226	.76	5.83
	......	70.1	28.3	22.9	115	111.2	978	1,182	.83	5.72
	......	71.6	28.2	22.3	112	112.4	940	(1,499)	(.63)	[1]5.59
	......	72.0	29.4	22.9	113	111.8	966	1,154	.84	5.60
Average..	10.5	70.7	28.0	22.5	111	111.6	952	1,180	.81	5.68

[1] Computed from the carbon dioxide for the period and the average of the respiratory quotients or the day.

TABLE 15.—*Metabolism of W. K. during grade walking in experiments without food.* (*Values per minute.*)—Continued.

Date.	Grade.	Distance.	Average respiration-rate.	Average pulmonary ventilation (reduced).	Average pulse-rate.	No. of steps.	Carbon dioxide.	Oxygen.	Respiratory quotient.	Heat (computed).
1915.	*p. ct.*	*meters.*		*liters.*			*c. c.*	*c. c.*		*cals.*
Apr. 22......	......	70.7	27.9	21.9	......	111.8	980	1,319	0.75	6.25
	......	70.9	28.7	21.6	108	111.8	963	1,224	.79	5.86
	......	72.2	29.4	22.2	117	112.8	987	1,243	.80	5.97
	......	72.0	29.8	21.7	111	111.8	997	1,311	.76	6.23
	......	71.3	29.2	21.8	110	111.2	941	1,258	.75	5.96
	......	71.7	29.4	21.4	113	111.8	961	1,251	.77	5.96
Average..	10.5	71.5	29.1	21.8	112	111.9	972	1,268	.77	6.04
Apr. 23......	......	70.7	27.7	22.7	......	110.6	975	1,207	.81	5.81
	......	71.2	27.9	22.8	111	111.0	945	1,183	.80	5.68
	......	71.4	28.0	22.4	119	111.0	938	1,207	.78	5.76
	......	71.3	28.2	21.6	120	110.0	911	1,281	.71	6.01
	......	71.8	28.1	22.1	120	110.8	932	1,265	.74	5.98
Average..	10.5	71.3	28.0	22.3	118	110.7	940	1,229	.76	5.84
Apr. 26......	......	74.9	28.5	24.4	128	116.4	1,055	1,239	.85	6.03
	......	75.5	28.8	24.4	133	116.4	1,043	1,232	.85	5.99
	......	75.9	29.0	24.5	142	116.0	1,036	1,250	.83	6.05
	......	76.3	28.3	22.0	......	115.6	1,008	1,285	.79	6.15
	......	76.6	29.5	23.0	......	116.2	1,017	1,276	.80	6.13
	......	77.5	30.3	23.1	......	117.2	1,064	1,259	.85	6.11
Average..	10.5	76.1	29.1	23.6	134	116.3	1,037	1,257	.82	6.07
Apr. 27......	......	76.2	28.8	23.2	118	117.2	1,066	1,276	.84	6.19
	......	76.9	28.7	23.1	122	115.8	1,054	1,288	.82	6.21
	......	77.1	29.2	22.8	128	115.8	1,062	1,314	.81	6.32
	......	76.9	29.2	23.0	130	115.6	1,088	1,206	.91	5.95
	......	77.4	30.1	22.7	131	116.0	1,050	1,386	.76	6.59
	......	77.8	31.0	23.1	131	116.8	1,070	1,280	.84	6.21
Average..	10.5	77.1	29.5	23.0	127	116.2	1,065	1,292	.82	6.23
Apr. 28......	......	75.6	28.2	21.8	117	114.4	1,039	1,417	.74	6.70
	......	76.1	28.3	22.2	117	114.2	1,039	1,317	.79	6.31
	......	76.7	28.5	22.3	121	115.2	1,044	1,242	.84	6.02
	......	77.1	29.8	22.7	127	115.4	1,054	1,254	.84	6.08
Average..	10.5	76.4	28.7	22.2	121	114.8	1,044	1,308	.80	6.28
Apr. 29......	......	75.1	28.0	23.5	115	113.0	1,043	1,249	.84	6.06
	......	75.8	28.3	24.1	119	113.8	1,044	1,202	.87	5.87
	......	76.0	28.4	24.4	......	114.4	1,051	1,212	.87	5.92
	......	76.8	28.7	23.8	127	115.2	1,068	1,215	.88	5.95
	......	77.1	28.5	23.7	128	115.8	1,048	1,265	.83	6.12
	......	76.9	28.8	24.0	......	115.6	1,057	1,311	.81	6.31
Average..	10.5	76.3	28.5	23.9	122	114.6	1,052	1,242	.85	6.04

TABLE 15.—*Metabolism of W. K. during grade walking in experiments without food. (Values per minute.)*—Continued.

Date.	Grade.	Distance.	Average respiration-rate.	Average pulmonary ventilation (reduced).	Average pulse-rate.	No. of steps.	Carbon dioxide.	Oxygen.	Respiratory quotient.	Heat (computed).
1915.	*p. ct.*	*meters.*		*liters.*			*c. c.*	*c. c.*		*cals.*
Apr. 30......	......	77.7	28.2	23.6	......	117.4	1,047	1,253	0.84	6.08
	......	78.8	29.2	24.1	119	119.0	1,075	1,297	.83	6.27
	......	79.9	29.0	24.4	124	119.8	1,118	1,335	.84	6.47
	......	80.2	29.2	24.3	124	119.6	1,105	(1,516)	(.73)	[1]6.50
	......	80.9	29.1	24.1	125	119.8	1,090	1,387	.79	6.64
	......	81.3	29.5	24.4	130	120.6	1,106	1,418	.78	6.77
Average..	10.5	79.8	29.0	24.2	124	119.4	1,090	1,338	.81	6.44
May 4......	......	77.0	28.2	22.3	......	117.2	1,083	1,277	.85	6.21
	......	78.1	27.4	21.7	......	117.2	1,078	1,363	.79	6.53
	......	78.4	27.5	21.4	......	118.0	1,080	1,272	.85	6.19
	......	78.6	26.8	22.0	......	117.6	1,104	1,267	.87	6.19
	......	79.1	27.6	21.3	......	119.2	1,094	1,463	.75	6 93
	......	79.3	27.7	21.6	......	119.0	1,115	1,321	.85	6.42
Average..	10.5	78.4	27.5	21.7	......	118.0	1,092	1,327	.82	6.40
May 5......	......	77.2	27.5	21.7	113	116.6	1,097	1,224	.90	6.03
	......	77.8	28.2	23.8	117	117.2	1,083	1,406	.77	6.70
	......	78.3	28.1	22.1	119	117.6	1,090	1,268	.86	6.18
	......	78.6	28.2	22.5	120	118.2	1,125	1,282	.88	6.28
	......	79.5	28.7	22.4	125	119.0	1,104	1,301	.85	6.33
	......	80.1	28.9	23.1	133	119.0	1,163	1,348	.87	6.57
Average..	10.5	78.6	28.3	22.6	121	117.9	1,110	1,305	.85	6.35
May 10......	......	53.6	23.7	21.1	......	94.8	1,011	1,159	.87	5.66
	......	54.0	24.2	21.4	......	99.8	975	1,174	.83	5.68
	......	55.0	24.5	20.9	......	98.6	1,045	1,244	.84	6.03
	......	55.7	24.8	20.9	......	100.2	1,046	1,269	.83	6.12
	......	56.0	26.1	21.5	......	103.0	974	1,282	.76	6.09
Average..	15.0	54.9	24.7	21.1	......	99.3	1,010	1,226	.82	5.92
May 11......	......	57.5	24.1	19.8	......	96.6	935	1,170	.80	5.62
	......	56.6	24.7	19.9	......	98.2	885	1,062	.84	5.14
	......	56.6	24.6	19.4	......	99.8	896	1,050	.86	5.11
	......	57.9	24.9	19.9	......	100.6	948	1,073	.89	5.27
	......	58.1	24.8	19.0	......	100.4	908	1,176	.77	5.60
	......	58.0	25.7	19.8	......	102.6	913	1,141	.80	5.48
Average..	13.0	57.5	24.8	19.6	......	99.7	914	1,112	.82	5.37
May 12......	......	58.3	25.7	21.0	......	103.4	928	1,170	.80	5.62
	......	58.4	25.9	21.0	......	105.6	901	1,099	.82	5.30
	......	58.6	26.0	21.6	......	105.2	988	1,119	.88	5.48
	......	59.0	26.1	20.2	......	106.2	945	1,109	.85	5.39
	......	58.9	26.3	20.0	......	106.0	893	1,143	.78	5.46
	......	59.1	26.8	20.0	......	105.4	907	1,134	.80	5.44
Average..	13.0	58.7	26.1	20.6	......	105.3	927	1,129	.82	5.45

[1] Computed from the carbon dioxide of the period and the average of the respiratory quotients for the day.

TABLE 15.—*Metabolism of W. K. during grade walking in experiments without food. (Values per minute.)*—Continued.

Date.	Grade.	Distance.	Average respiration-rate.	Average pulmonary ventilation (reduced).	Average pulse-rate	No. of steps.	Carbon dioxide.	Oxygen.	Respiratory quotient.	Heat (computed).
1915.	*p. ct.*	*meters.*		*liters.*			*c. c.*	*c. c.*		*cals.*
May 13......	......	60.4	26.9	25.1	119	106.0	1,127	1,356	0.83	6.56
	......	60.2	28.4	25.3	125	107.4	1,110	1,401	.79	6.71
	......	59.8	29.0	25.1	128	107.8	1,116	1,430	.78	6.83
	......	59.9	29.3	23.6	......	105.6	1,142	1,382	.83	6.69
	......	59.5	29.0	23.0	......	107.2	1,103	1,294	.86	6.31
	......	59.2	28.6	22.5	......	105.0	1,081	1,309	.83	6.33
Average..	15.0	59.8	28.5	24.1	124	106.5	1,113	1,362	.82	6.57
May 14......	......	56.8	26.2	25.0	111	104.8	1,089	1,219	.89	5.99
	......	54.9	27.1	24.1	112	104.8	1,042	1,199	.87	5.86
	......	54.8	27.7	24.2	120	103.8	1,032	1,193	.87	5.83
	......	55.3	27.7	22.3	117	102.2	1,047	1,182	.89	5.81
	......	55.2	27.4	21.7	116	104.4	1,024	....	......	[1]5.70
Average..	15.3	55.4	27.2	23.5	115	104.0	1,047	1,198	.87	5.85
May 17......	......	57.7	27.2	23.5	120	110.4	1,115	1,302	.86	6.35
	......	58.2	27.9	23.5	126	111.2	1,103	1,295	.85	6.30
	......	57.6	28.3	23.0	128	111.2	1,098	1,291	.85	6.28
	......	57.6	28.0	22.4	129	109.2	1,075	1,289	.84	6.25
	......	57.6	28.3	23.1	132	111.0	1,074	1,312	.82	6.33
Average..	15.3	57.7	27.9	23.1	127	110.6	1,093	1,298	.84	6.30
May 18......	......	60.3	27.5	26.4	115	109.8	1,169	1,301	.90	6.41
	......	60.2	27.6	26.2	112	109.8	1,156	1,318	.88	6.46
	......	60.1	27.9	26.4	118	111.8	1,157	1,326	.87	6.48
	......	59.6	27.3	25.4	117	105.0	1,142	1,299	.88	6.37
	......	59.3	27.6	24.7	117	104.8	1,107	1,288	.86	6.28
	......	58.7	27.3	24.7	120	107.8	1,099	1,301	.85	6.33
Average..	15.4	59.7	27.5	25.6	117	108.2	1,138	1,306	.87	6.38
May 24......	......	65.5	28.2	26.5	129	115.8	1,286	1,468	.88	7.19
	......	65.6	28.0	25.9	133	114.8	1,279	1,492	.86	7.27
	......	65.7	28.7	26.8	136	117.0	1,292	1,419	.91	7.00
	......	66.0	28.3	25.8	137	114.0	1,292	1,436	.90	7.07
	......	66.3	28.4	....	148	114.6	1,261	....	......	[1]6.96
	......	66.6	29.1	25.7	151	115.2	1,289	1,468	.88	7.19
Average..	15.3	66.0	28.5	26.1	139	115.2	1,283	1,457	.88	7.14
May 25......	......	66.4	29.2	29.3	130	116.6	1,322	1,456	.91	7.19
	......	67.4	29.0	29.4	134	116.4	1,300	1,502	.87	7.34
	......	66.9	28.7	29.1	135	115.6	1,304	1,480	.88	7.25
	......	66.8	28.5	26.4	134	112.6	1,305	1,473	.89	7.24
	......	66.6	28.5	25.3	138	110.8	1,258	1,471	.86	7.17
	......	66.5	29.4	25.5	143	111.6	1,267	(1,668)	(.76)	[1]7.05
Average..	15.3	66.8	28.9	27.5	136	113.9	1,293	1,476	.88	7.23

---

[1] Computed from the carbon dioxide of the period and the average of the respiratory quotients for the day.

TABLE 15.—*Metabolism of W. K. during grade walking in experiments without food. (Values per minute.)*—Continued.

Date.	Grade.	Distance.	Average respiration-rate.	Average pulmonary ventilation (reduced)	Average pulse-rate.	No. of steps.	Carbon dioxide.	Oxygen.	Respiratory quotient.	Heat (computed).
1915.	*p. ct.*	*meters.*		*liters.*			*c. c.*	*c. c.*		*cals.*
May 26......	......	77.6	30.0	31.0	134	121.3	1,549	1,656	0.94	8.24
	......	78.9	31.0	32.3	143	122.8	1,553	1,853	.84	8.99
	......	79.2	31.9	32.4	146	121.3	1,578	1,733	.91	8.55
	......	79.7	31.1	30.9	143	120.0	1,577	1,917	.83	9.28
	......	80.3	32.8	31.5	......	121.3	1,560	1,908	.82	9.21
	......	80.7	32.9	32.2	......	121.5	1,573	1,795	.88	8.80
Average..	15.3	79.4	31.6	31.7	142	121.4	1,565	1,810	.86	8.82
May 28......	......	78.1	29.9	29.8	128	119.5	1,529	1,627	.94	8.09
	......	78.9	30.2	29.1	136	119.0	1,478	1,648	.90	8.11
	......	79.4	29.8	30.0	138	123.0	1,510	1,672	.91	8.25
	......	79.8	28.7	28.7	137	119.8	1,517	1,687	.90	8.31
	......	80.7	30.6	29.7	147	121.8	1,534	1,740	.88	8.53
	......	80.9	31.4	30.2	152	122.0	1,552	1,771	.88	8.68
Average..	15.3	79.6	30.1	29.6	140	120.9	1,520	1,691	.90	8.33
May 29......	......	79.0	29.4	32.1	135	119.0	1,516	1,676	.91	8.28
	......	80.0	30.7	33.0	146	122.3	1,537	1,721	.90	8.48
	......	80.4	32.1	34.3	149	122.5	1,583	1,752	.91	8.65
Average..	15.3	79.8	30.7	33.1	143	121.3	1,545	1,716	.90	8.45
June 1......	......	80.6	29.5	31.7	148	119.5	1,570	1,698	.93	8.42
	......	80.2	31.7	32.7	155	121.2	1,601	1,735	.93	8.61
	......	80.6	32.9	33.5	160	122.8	1,614	1,757	.92	8.69
Average..	15.3	80.5	31.4	32.6	154	121.2	1,595	1,730	.92	8.56
June 2......	......	79.1	29.9	31.6	140	120.5	1,572	1,697	.93	8.42
	......	79.8	31.4	32.7	147	122.0	1,579	1,711	.92	8.49
	......	80.4	33.0	33.6	151	123.5	1,626	1,757	.93	8.71
Average..	15.3	79.8	31.4	32.6	146	122.0	1,592	1,722	.92	8.52
June 7......	......	49.9	25.6	25.1	......	100.8	1,228	1,381	.89	6.78
	......	50.1	26.4	24.9	......	102.6	1,237	1,410	.88	6.91
	......	48.8	26.6	25.9	129	102.4	1,200	1,372	.88	6.72
	......	47.9	27.6	23.4	126	98.0	1,175	1,324	.89	6.50
	......	47.8	27.4	24.1	......	102.4	1,150	1,353	.85	6.58
	......	47.3	29.0	24.9	139	104.2	1,179	1,369	.86	6.67
Average..	20.0	48.6	27.1	24.7	131	101.7	1,195	1,368	.87	6.69
June 8......	......	46.7	26.6	25.0	......	97.4	1,127	1,308	.86	6.38
	......	45.1	32.1	25.6	......	97.4	1,095	1,286	.85	6.25
	......	43.9	29.1	24.6	......	95.2	1,070	1,257	.85	6.11
	......	50.5	31.7	27.7	134	102.4	1,208	1,423	.85	6.92
	......	50.4	29.8	28.0	141	104.2	1,242	1,451	.86	7.07
	......	50.0	31.3	28.6	146	106.0	1,253	1,464	.86	7.14
Average..	20.0	47.8	30.1	26.6	140	100.4	1,166	1,365	.85	6.64

TABLE 15.—*Metabolism of W. K. during grade walking in experiments without food. (Values per minute.)*—Continued.

Date.	Grade.	Distance.	Average respiration-rate.	Average pulmonary ventilation (reduced).	Average pulse-rate.	No. of steps.	Carbon dioxide.	Oxygen.	Respiratory quotient.	Heat (computed).
1915.	*p. ct.*	*meters.*		*liters.*			*c. c.*	*c. c.*		*cals.*
June 9......	......	57.3	28.6	29.6	......	110.6	1,335	1,540	0.87	7.53
	......	56.9	29.2	29.7	......	108.8	1,306	1,526	.86	7.44
	......	56.9	30.9	30.3	......	111.8	1,325	1,577	.84	7.65
	......	58.0	30.9	28.0	141	112.8	1,308	1,642	.80	7.88
	......	57.0	31.9	28.0	145	113.4	1,305	1,602	.82	7.73
	......	57.0	32.7	29.2	149	114.4	1,338	1,583	.85	7.70
Average..	20.0	57.2	30.7	29.1	145	112.0	1,320	1,578	.84	7.65
June 10......	......	63.4	31.8	34.6	......	116.6	1,497	1,703	.88	8.34
	......	63.0	33.0	35.3	......	117.6	1,491	1,726	.87	8.43
	......	62.9	33.5	36.2	154	118.4	1,488	1,719	.87	8.40
	......	64.0	33.4	33.7	150	117.0	1,513	1,758	.86	8.57
	......	63.8	34.0	34.7	159	117.2	1,499	1,759	.85	8.55
	......	63.4	36.6	35.6	159	117.2	1,501	1,741	.86	8.49
Average..	20.0	63.4	33.7	35.0	156	117.3	1,498	1,734	.86	8.45
June 11......	......	73.2	32.6	39.5	......	122.8	1,787	1,957	.92	9.68
	......	73.4	35.8	45.9	......	123.0	1,793	1,978	.91	9.76
	......	74.0	35.2	41.5	158	124.0	1,795	1,993	.90	9.81
	......	69.0	35.0	40.0	162	121.5	1,614	1,869	.87	9.13
	......	68.3	36.3	42.0	167	122.8	1,655	1,860	.89	9.14
Average..	20.0	71.6	35.0	41.8	162	122.8	1,729	1,931	.90	9.51
June 12......	......	73.5	31.8	39.9	153	120.3	1,749	1,929	.91	9.52
	......	74.6	36.2	42.9	......	121.5	1,765	2,014	.88	9.87
	......	74.4	38.4	44.2	162	121.0	1,748	2,004	.87	9.79
	......	74.0	34.8	41.0	......	120.5	1,737	1,948	.89	9.57
	......	74.0	36.1	42.0	163	123.0	1,704	1,974	.86	9.62
	......	74.0	37.7	43.2	164	122.5	1,725	1,992	.87	9.73
Average..	20.0	74.1	35.8	42.2	161	121.5	1,738	1,977	.88	9.69
June 14......	......	78.8	39.4	45.3	158	123.0	1,869	2,010	.93	9.97
	......	79.8	39.6	47.4	169	126.8	1,906	2,052	.93	10.18
	......	80.0	41.1	49.8	174	126.8	1,950	2,085	.94	10.37
Average..	20.0	79.5	40.0	47.5	167	125.5	1,908	2,049	.93	10.16
June 15......	......	57.2	30.6	37.1	......	114.0	1,646	1,827	.90	9.00
	......	55.0	33.9	34.7	141	110.0	1,544	1,760	.88	8.62
	......	54.6	32.9	33.3	140	109.0	1,517	1,751	.87	8.56
	......	54.4	34.1	33.9	141	109.8	1,534	1,723	.89	8.46
	......	53.1	33.6	32.8	142	109.4	1,447	1,737	.84	8.42
	......	53.1	34.2	32.9	145	108.4	1,449	1,731	.84	8.40
Average..	25.0	54.6	33.2	34.1	142	110.1	1,523	1,755	.87	8.58

TABLE 15.—*Metabolism of W. K. during grade walking in experiments without food. (Values per minute.)*—Continued.

Date.	Grade.	Distance.	Average respiration-rate.	Average pulmonary ventilation (reduced).	Average pulse-rate.	No. of steps.	Carbon dioxide.	Oxygen.	Respiratory quotient.	Heat (computed).
1915.	*p. ct.*	*meters.*		*liters.*			*c. c.*	*c. c.*		*cals.*
June 16......	......	59.9	32.9	41.5	153	114.4	1,688	1,902	0.89	9.34
	......	58.7	36.9	41.5	154	116.0	1,626	1,861	.88	9.12
	......	57.4	36.4	41.0	155	114.6	1,587	1,837	.87	8.98
	......	51.8	34.4	37.2	149	109.4	1,443	1,690	.86	8.24
	......	50.9	33.1	35.0	150	107.6	1,359	1,657	.82	8.00
	......	50.1	33.4	34.6	151	108.6	1,343	1,635	.82	7.89
Average..	25.0	54.8	34.5	38.5	152	111.8	1,508	1,764	.85	8.58
June 17......	......	67.6	36.5	48.9	165	122.0	1,968	2,118	.93	10.51
	......	66.8	38.8	50.7	170	120.0	1,887	2,115	.89	10.39
	......	66.4	38.3	50.5	164	117.8	1,921	2,077	.93	10.30
	......	66.6	38.8	49.7	166	121.8	1,891	2,103	.90	10.36
Average..	25.0	66.9	38.1	50.0	166	120.4	1,917	2,103	.91	10.38
June 23.....	......	70.5	37.2	52.5	170	123.0	2,084	2,045	1.02	[1]10.32
	......	72.4	42.7	60.0	181	123.0	2,220	2,142	1.04	[1]10.81
Average..	25.0	71.5	40.0	56.3	176	123.0	2,152	2,094	1.03	[1]10.57

[1] Respiratory quotient of 1.00 used in computing.

TABLE 16.—*Metabolism of E. D. B. during grade walking in experiments without food. (Values per minute.)*

Date.	Grade.	Distance.	Average respiration-rate.	Average pulmonary ventilation (reduced).	Average pulse-rate.	No. of steps.	Carbon dioxide.	Oxygen.	Respiratory quotient.	Heat (computed).
1915.	*p. ct.*	*meters.*		*liters.*			*c. c.*	*c. c.*		*cals.*
Oct. 30......	......	39.8	18.6	13.2	......	75.8	518	589	0.88	2.89
	......	38.4	18.9	12.6	......	74.6	483	602	.80	2.89
	......	37.9	18.8	12.8	......	75.0	485	593	.82	2.86
	......	37.9	18.7	12.8	......	73.4	488	605	.81	2.91
Average..	5	38.5	18.8	12.9	......	74.7	494	597	.83	2.89
Nov. 1.....	......	49.4	19.9	14.6	......	83.2	581	650	.89	3.19
	......	48.8	19.5	14.3	......	82.8	580	644	.90	3.17
	......	48.6	20.3	14.7	......	82.4	573	658	.87	3.22
	......	47.8	19.9	14.5	......	82.2	570	671	.85	3.26
Average..	5	48.7	19.9	14.5	......	82.7	576	656	.88	3.21

TABLE 16.—*Metabolism of E. D. B. during grade walking in experiments without food.* (*Values per minute.*)—Continued.

Date.	Grade.	Distance.	Average respiration-rate.	Average pulmonary ventilation (reduced).	Average pulse-rate.	No. of steps.	Carbon dioxide.	Oxygen.	Respiratory quotient.	Heat (computed).
1915.	*p. ct.*	*meters.*		*liters.*			*c. c.*	*c. c.*		*cals.*
Nov. 2......	......	41.0	19.6	13.3	......	79.8	520	614	0.85	2.99
	......	40.5	20.1	13.1	88	78.6	507	614	.83	2.97
	......	40.4	20.4	13.1	......	79.6	515	631	.81	3.04
	......	41.7	19.8	13.0	......	79.8	513	622	.83	3.01
Average..	5	40.9	20.0	13.1	88	79.5	514	620	.83	3.00
Nov. 3......	......	43.1	20.0	13.8	......	77.6	536	610	.88	2.99
	......	42.3	20.1	13.2	......	74.6	507	617	.82	2.98
	......	42.1	19.9	13.4	......	78.4	508	622	.82	3.00
	......	41.5	20.3	13.1	......	77.8	503	626	.80	3.01
Average..	5	42.3	20.1	13.4	......	77.1	514	619	.83	2.99
Nov. 4......	......	48.3	20.3	14.3	......	81.6	538	659	.82	3.18
	......	48.5	20.0	14.1	......	79.0	535	652	.82	3.15
	......	48.1	19.9	14.1	......	79.6	529	645	.82	3.11
	......	47.7	19.8	14.0	......	79.4	534	658	.81	3.17
Average..	5	48.2	20.0	14.1	......	79.9	534	654	.82	3.16
Nov. 5......	......	44.0	20.1	13.7	77	79.2	517	612	.84	2.97
	......	42.6	20.3	13.7	81	77.0	508	620	.82	2.99
	......	41.3	19.2	12.6	84	75.2	506	618	.82	2.98
	......	42.0	19.4	13.4	86	75.0	506	623	.81	3.00
Average..	5	42.5	19.8	13.4	82	76.6	509	618	.82	2.98
Nov. 6......	......	49.5	20.0	14.4	81	80.6	556	618	.90	3.04
	......	49.1	21.1	15.0	83	80.2	574	638	.90	3.14
	......	47.9	20.1	14.1	87	79.2	538	622	.87	3.04
	......	47.9	19.6	13.8	89	79.8	532	611	.87	2.99
	......	46.7	19.7	13.8	93	77.6	536	630	.85	3.06
Average..	5	48.2	20.1	14.2	87	79.5	547	624	.88	3.06
Nov. 8......	......	53.5	21.0	15.4	......	84.4	614	654	.94	3.25
	......	52.3	20.8	15.2	......	83.0	582	655	.89	3.22
	......	52.3	20.8	14.8	......	86.0	591	669	.88	3.28
	......	51.8	20.0	14.8	......	82.2	572	664	.86	3.24
Average..	5	52.5	20.7	15.1	......	83.9	590	661	.89	3.25
Nov. 9......	......	55.6	21.1	15.0	......	85.0	583	686	.85	3.34
	......	54.9	20.6	14.3	......	84.4	569	673	.85	3.27
	......	54.6	21.2	14.9	......	84.8	571	698	.82	3.37
	......	53.9	21.0	14.5	......	83.6	561	687	.82	3.31
Average..	5	54.8	21.0	14.7	......	84.5	571	686	.83	3.32

TABLE 16.—*Metabolism of E. D. B. during grade walking in experiments without food. (Values per minute.)*—Continued.

Date.	Grade.	Distance.	Average respiration-rate.	Average pulmonary ventilation (reduced).	Average pulse-rate.	No. of steps.	Carbon dioxide.	Oxygen.	Respiratory quotient.	Heat (computed).
1915.	*p. ct.*	*meters.*		*liters.*			*c. c.*	*c. c.*		*cals.*
Nov. 10.....	......	57.3	22.4	15.9	86	88.0	587	684	0.86	3.33
	......	56.5	22.9	15.8	......	87.6	577	694	.83	3.36
	......	54.0	22.5	14.9	......	86.0	546	669	.82	3.23
	......	53.7	22.1	14.5	95	85.0	538	654	.82	3.16
Average..	5	55.4	22.5	15.3	91	86.7	562	675	.83	3.27
Nov. 11.....	......	67.1	22.9	17.2	96	96.0	666	765	.87	3.74
	......	65.8	23.3	16.8	......	95.6	647	776	.83	3.75
	......	65.9	22.8	17.1	......	94.6	661	784	.84	3.80
	......	65.3	23.0	17.3	105	93.8	672	800	.84	3.88
Average..	5	66.0	23.0	17.1	101	95.0	662	781	.85	3.80
Nov. 12.....	......	65.6	23.4	17.2	94	95.2	665	758	.88	3.71
	......	65.4	22.9	17.2	......	95.2	676	789	.86	3.85
	......	65.7	23.4	16.9	......	94.6	654	782	.84	3.79
	......	64.8	22.8	16.9	103	94.6	656	782	.84	3.79
Average..	5	65.4	23.1	17.1	99	94.9	663	778	.85	3.78
Nov. 13.....	......	74.0	24.5	19.3	99	100.2	761	849	.90	4.18
	......	74.1	23.8	19.0	......	99.4	753	891	.84	4.32
	......	74.0	24.1	18.7	......	99.6	733	882	.83	4.27
	......	74.2	24.8	18.3	104	100.2	697	860	.81	4.14
Average..	5	74.1	24.3	18.8	102	99.9	736	871	.85	4.24
Nov. 15.....	......	74.8	23.7	18.7	99	100.2	795	843	.94	4.19
	......	75.0	24.9	19.4	......	101.4	785	865	.91	4.27
	......	75.0	24.7	18.7	106	101.2	775	874	.89	4.29
	......	75.1	25.3	18.5	108	101.4	772	873	.89	4.29
Average..	5	75.0	24.7	18.8	104	101.1	782	864	.91	4.26
Nov. 16.....	......	70.1	23.2	18.3	96	99.2	693	823	.84	3.99
	......	75.1	24.2	18.5	......	102.8	706	868	.81	4.18
	......	75.3	24.3	18.2	......	102.8	703	871	.81	4.19
	......	74.7	24.7	18.1	105	100.6	702	870	.81	4.19
Average..	5	73.8	24.1	18.3	101	101.4	701	858	.82	4.14
Nov. 17.....	......	48.7	23.9	19.5	99	81.6	746	870	.86	4.24
	......	48.5	24.4	19.5	......	81.4	736	889	.83	4.30
	......	47.6	23.7	18.7	......	81.2	738	882	.84	4.28
	......	47.3	25.1	19.5	110	80.2	740	890	.83	4.31
Average..	10.3	48.0	24.3	19.3	105	81.1	740	883	.84	4.28
Nov. 22.....	......	42.5	20.2	17.0	......	77.8	693	786	.88	3.85
	......	41.5	20.9	16.7	......	78.0	670	794	.84	3.85
	......	41.5	21.4	16.9	......	77.4	665	817	.81	3.93
	......	41.5	22.2	17.2	......	77.6	673	825	.82	3.98
Average..	10.3	41.8	21.2	17.0	......	77.7	675	806	.84	3.91

Table 16.—*Metabolism of E. D. B. during grade walking in experiments without food. (Values per minute.)*—Continued.

Date.	Grade.	Distance.	Average respiration-rate.	Average pulmonary ventilation (reduced).	Average pulse-rate.	No. of steps.	Carbon dioxide.	Oxygen.	Respiratory quotient.	Heat (computed).
1915.	*p. ct.*	*meters.*		*liters.*			*c. c.*	*c. c.*		*cals.*
Nov. 23.....	......	57.8	23.5	21.9	102	87.6	834	971	0.86	4.73
	......	57.0	24.2	22.2	......	87.4	886	991	.89	4.87
	......	57.1	24.5	21.6	114	87.4	839	1,001	.84	4.85
	......	56.8	23.4	21.1	117	86.2	857	1,007	.85	4.90
Average..	10.0	57.2	23.9	21.7	111	87.2	854	993	.86	4.84
Nov. 24.....	......	56.5	22.2	20.7	100	85.4	835	966	.86	4.71
	......	57.4	23.0	20.9	......	86.0	852	1,011	.84	4.90
	......	58.3	23.4	21.7	......	87.2	873	1,031	.85	5.01
	......	57.4	22.4	20.2	116	86.2	839	1,021	.82	4.93
Average..	10.0	57.4	22.8	20.9	108	86.2	850	1,007	.84	4.88
Nov. 26.....	......	66.1	21.8	21.0	......	92.6	1,027	1,100	.93	5.46
	......	66.6	23.1	21.3	......	94.2	1,041	1,118	.93	5.55
	......	66.8	22.9	21.3	......	97.2	1,043	1,149	.91	5.67
	......	66.6	23.4	21.2	......	93.2	1,048	1,155	.91	5.70
Average..	10.0	66.5	22.8	21.2	......	94.3	1,040	1,131	.92	5.60
Nov. 27.....	......	66.1	22.6	22.4	......	94.6	(936)	1,093	[1](.87)	5.34
	......	65.7	24.0	22.6	......	91.6	1,006	1,112	.90	5.48
	......	66.0	23.7	21.9	......	95.6	991	1,128	.88	5.53
	......	65.8	23.6	21.8	......	95.8	983	1,147	.86	5.59
	......	65.9	24.7	21.9	......	97.4	980	1,159	.85	5.64
Average..	10.0	65.9	23.7	22.1	......	95.0	990	1,128	.88	5.53
Nov. 29.....	......	65.6	24.1	23.5	110	97.6	993	1,100	.90	5.42
	......	65.4	24.3	23.4	......	96.6	985	1,135	.87	5.55
	......	65.8	24.3	22.7	......	95.4	988	1,167	.85	5.68
	......	65.6	24.1	27.1	132	96.2	962	1,180	.82	5.69
Average..	10.0	65.6	24.3	24.2	121	96.5	982	1,146	.86	5.59
Nov. 30.....	......	77.6	24.5	26.9	113	100.6	1,189	1,345	.88	6.59
	......	78.4	26.4	27.2	......	101.8	1,183	1,373	.86	6.69
	......	78.8	25.9	27.9	......	102.0	1,183	1,378	.86	6.72
	......	79.0	26.7	28.1	136	102.2	1,207	1,402	.86	6.83
Average..	10.0	78.5	25.9	27.5	125	101.7	1,191	1,375	.87	6.72
Dec. 1......	......	79.3	24.9	27.2	120	103.8	1,200	1,284	.93	6.37
	......	80.1	26.6	28.7	......	104.4	1,209	1,341	.90	6.60
	......	80.6	26.9	28.8	......	104.2	1,201	1,362	.88	6.67
	......	80.0	25.9	28.8	......	105.0	1,194	1,397	.85	6.79
Average..	10.0	80.0	26.1	28.4	120	104.4	1,201	1,346	.89	6.61

---

[1] Assumed.

TABLE 16.—*Metabolism of E. D. B. during grade walking in experiments without food. (Values per minute.)*—Continued.

Date.	Grade.	Distance.	Average respiration-rate.	Average pulmonary ventilation (reduced).	Average pulse-rate.	No. of steps.	Carbon dioxide.	Oxygen.	Respiratory quotient.	Heat (computed).
1915.	*p. ct.*	*meters.*		*liters.*			*c. c.*	*c. c.*		*cals.*
Dec. 2	......	68.7	25.1	25.0	108	97.4	1,063	1,117	.95	5.57
	......	68.7	24.7	25.2	117	97.8	1,054	1,151	.92	5.70
	......	68.1	24.7	24.0	122	96.8	1,038	1,161	.89	5.70
	......	67.6	23.4	23.4	124	97.4	1,018	1,162	.88	5.69
Average	10.0	68.3	24.5	24.4	118	97.4	1,043	1,148	.91	5.67
Dec. 3	......	70.7	24.7	24.2	112	97.0	1,089	1,189	.92	5.88
	......	70.8	26.5	26.3	116	97.8	1,084	1,205	.90	5.93
	......	70.2	25.0	25.5	120	96.8	1,059	1,218	.87	5.95
	......	70.4	25.3	24.4	124	98.4	1,065	1,236	.86	5.03
Average	10.0	70.5	25.4	25.1	118	97.5	1,074	1,212	.89	5.95
Dec. 4	......	44.8	23.6	22.2	......	78.8	936	1,020	.92	5.05
	......	44.7	23.8	22.1	......	78.4	916	1,036	.88	5.08
	......	44.2	24.5	21.9	......	78.8	894	1,039	.86	5.07
	......	44.0	23.2	21.3	......	78.0	881	1,042	.85	5.07
Average	15.0	44.4	23.8	21.9	......	78.5	907	1,034	.88	5.07
Dec. 6	......	41.5	22.6	21.0	101	77.0	866	950	.91	4.69
	......	39.1	22.7	20.6	107	76.4	834	930	.90	4.58
	......	38.3	24.0	20.7	108	74.8	819	910	.90	4.48
	......	37.1	23.0	20.3	110	75.6	805	903	.89	4.44
Average	15.0	39.0	23.1	20.7	107	76.0	831	923	.90	4.54
Dec. 7	......	48.0	24.7	23.7	110	83.0	976	1,075	.91	5.31
	......	46.9	26.3	23.6	118	81.6	945	1,060	.89	5.21
	......	44.4	25.6	22.5	117	79.2	894	1,020	.88	5.00
Average	15.0	46.4	25.5	23.3	115	81.3	938	1,052	.89	5.17
Dec. 8	......	57.5	25.1	26.1	122	......	1,099	1,247	.88	6.11
	......	58.6	27.2	27.0	131	......	1,102	1,314	.84	6.37
	......	58.5	27.4	32.4	134	89.2	1,096	1,326	.83	6.42
	......	57.9	26.4	26.0	133	89.0	1,088	1,285	.85	6.25
	......	58.4	26.4	26.0	......	89.0	1,072	1,340	.80	6.43
	......	59.1	27.5	27.3	......	90.4	1,100	1,371	.80	6.58
Average	15.0	58.3	26.7	27.5	130	89.4	1,093	1,314	.83	6.36
Dec. 13	......	67.3	25.5	28.8	123	98.0	1,233	1,396	.88	6.84
	......	67.2	26.0	29.4	131	98.0	1,234	1,443	.86	7.03
	......	66.0	26.1	29.2	138	96.9	1,200	1,419	.85	6.90
Average	15.0	66.8	25.9	29.1	131	97.6	1,222	1,419	.86	6.92

TABLE 16.—*Metabolism of E. D. B. during grade walking in experiments without food. (Values per minute.)*—Continued.

Date.	Grade.	Distance.	Average respiration-rate.	Average pulmonary ventilation (reduced).	Average pulse-rate.	No. of steps.	Carbon dioxide.	Oxygen.	Respiratory quotient.	Heat (computed).
1915.	*p. ct.*	*meters.*		*liters.*			*c. c.*	*c. c.*		*cals.*
Dec. 14......	......	73.8	24.3	31.2	113	104.4	1,389	1,544	0.90	7.60
	......	74.0	27.2	31.2	127	103.2	1,368	1,571	.87	7.68
	......	73.5	27.4	32.7	129	100.8	1,332	1,553	.86	7.57
	......	72.8	27.9	32.7	129	101.5	1,331	1,535	.87	7.50
	......	73.1	27.1	30.2	140	102.0	1,322	1,616	.82	7.80
Average..	15.0	73.4	26.8	31.6	128	102.4	1,348	1,564	.86	7.62
Dec. 15......	......	75.0	22.9	28.8	113	105.6	1,376	1,575	.87	7.70
	......	75.1	25.8	30.3	120	104.8	1,341	1,602	.84	7.77
	......	74.9	26.1	30.0	125	105.0	1,326	1,592	.83	7.70
	......	74.8	24.5	29.8	126	103.2	1,344	1,560	.86	7.60
	......	75.3	26.5	29.5	132	104.2	1,312	1,621	.81	7.80
	......	76.0	26.9	31.3	136	105.6	1,335	1,655	.81	7.97
Average..	15.0	75.2	25.5	30.0	125	104.7	1,339	1,601	.84	7.76
Dec. 16......	......	80.3	25.4	33.6	124	107.0	1,497	1,671	.90	8.23
	......	81.0	26.4	34.2	130	107.0	1,480	1,668	.89	8.19
	......	81.4	26.4	33.9	......	107.2	1,501	1,738	.86	8.47
	......	80.6	24.8	32.0	134	107.0	1,460.	1,649	.89	8.10
	......	82.2	27.6	33.5	139	107.8	1,472	1,767	.83	8.55
	......	82.0	27.3	33.8	144	106.8	1,476	1,780	.83	8.61
Average..	15.0	81.3	26.3	33.5	134	107.1	1,481	1,712	.87	8.37
Dec. 17......	......	54.7	24.4	27.8	113	90.8	1,204	1,354	.89	6.65
	......	54.4	24.4	27.6	119	89.2	1,171	1,386	.85	6.74
	......	52.0	24.0	25.8	118	88.0	1,110	1,334	.83	6.45
	......	53.4	25.2	26.6	123	89.4	1,130	1,378	.82	6.65
	......	53.6	23.2	26.0	126	88.7	1,130	1,374	.82	6.63
	......	52.2	24.9	26.6	128	86.2	1,130	1,384	.82	6.68
Average..	20.0	53.4	24.4	26.7	121	88.7	1,146	1,368	.84	6.63
Dec. 18......	......	39.7	22.2	21.9	......	77.2	952	1,067	.89	5.24
	......	37.8	22.9	21.2	......	76.8	864	1,042	.83	5.04
	......	37.6	24.6	21.5	......	78.2	870	1,044	.83	5.05
	......	45.8	23.2	24.0	110	82.6	1,037	1,167	.89	5.73
	......	45.3	23.3	23.1	110	82.6	982	1,190	.83	5.76
	......	44.4	23.8	22.9	108	82.4	970	1,170	.83	5.66
Average..	20.0	41.8	23.3	22.4	109	80.0	946	1,113	.85	5.41
Dec. 20......	......	65.6	24.9	33.4	119	100.2	1,523	1,614	.94	8.03
	......	65.8	24.9	33.4	127	99.6	1,499	1,634	.92	8.09
	......	66.0	26.1	34.6	131	100.2	1,491	1,641	.91	8.10
	......	66.4	24.9	34.4	......	100.6	1,521	1,626	.94	8.09
	......	67.5	25.7	34.8	......	102.6	1,521	1,735	.88	8.50
	......	67.1	25.4	34.1	......	101.0	1,514	1,748	.87	8.54
Average..	20.0	66.4	25.3	34.1	126	100.7	1,512	1,666	.91	8.22

TABLE 16.—*Metabolism of E. D. B. during grade walking in experiments without food. (Values per minute.)*—Continued.

Date.	Grade.	Distance.	Average respiration-rate.	Average pulmonary ventilation (reduced).	Average pulse-rate.	No. of steps.	Carbon dioxide.	Oxygen.	Respiratory quotient.	Heat (computed).
1915.	*p. ct.*	*meters.*		*liters.*			*c. c.*	*c. c.*		*cals.*
Dec. 21......	......	69.4	25.5	35.4	......	103.0	1,602	1,706	0.94	8.48
	......	70.5	26.1	35.7	......	106.4	1,602	1,808	.89	8.88
	......	70.9	26.4	39.8	......	105.4	1,584	1,839	.86	8.97
Average..	20.0	70.3	26.0	37.0	......	104.9	1,596	1,784	.90	8.78
Dec. 22......	......	69.4	24.6	33.4	......	104.4	1,544	1,715	.90	8.44
	......	69.5	26.6	34.4	......	104.8	1,550	1,746	.89	8.58
	......	71.2	25.8	34.7	......	106.6	1,569	1,784	.88	8.74
Average..	20.0	70.0	25.7	34.2	......	105.3	1,554	1,748	.89	8.59
Dec. 31......	......	79.6	24.9	41.6	......	109.8	2,025	2,217	.91	10.94
	......	80.6	30.3	46.1	......	110.6	2,058	2,322	.89	11.41
Average..	20.0	80.1	27.6	43.9	......	110.2	2,042	2,270	.90	11.18
1916. Jan. 1.......	......	79.3	26.9	41.3	......	110.0	1,949	2,162	.90	10.65
	......	80.1	27.7	43.8	......	112.6	2,001	2,281	.88	11.18
	......	81.6	28.1	47.0	......	112.6	2,080	2,373	.88	11.63
Average..	20.0	80.3	27.6	44.0	......	111.7	2,010	2,272	.88	11.13
Jan. 3.......	......	43.1	23.4	27.5	......	85.6	1,184	1,453	.82	7.01
	......	42.5	24.1	31.8	......	84.0	1,181	1,456	.81	7.01
	......	42.3	24.0	28.0	......	85.0	1,183	1,444	.82	6.97
Average..	25.0	42.6	23.8	29.1	......	84.9	1,183	1,451	.82	7.00
Jan. 4.......	......	59.2	24.6	37.0	......	97.2	1,730	1,909	.91	9.42
	......	60.5	24.8	37.5	......	96.0	1,705	1,954	.87	9.55
	......	60.4	25.7	38.7	......	94.6	1,729	1,998	.87	9.76
	......	60.1	29.1	48.8	......	96.2	1,728	1,999	.86	9.75
Average..	25.0	60.1	26.1	40.5	......	96.0	1,723	1,965	.88	9.63
Jan. 5.......	......	69.5	27.2	45.5	......	105.6	2,037	2,281	.89	11.20
	......	69.1	28.1	50.7	......	103.4	2,070	2,223	.93	11.03
Average..	25.0	69.3	27.7	48.1	......	104.5	2,054	2,252	.91	11.12
Feb. 2.......	......	45.3	22.1	30.8	132	86.0	1,385	1,558	.89	7.65
	......	46.6	22.1	33.0	144	84.4	1,500	1,667	.90	8.21
	......	47.5	23.7	36.0	159	87.2	1,574	1,778	.89	8.73
Average..	25.0	46.5	22.6	33.3	145	85.9	1,486	1,668	.89	8.19
Feb. 3.......	......	51.6	22.4	32.9	140	91.4	1,556	1,730	.90	8.52
	......	53.6	26.9	37.2	149	93.2	1,610	1,863	.86	9.08
	......	52.7	25.0	35.7	156	91.4	1,560	1,822	.86	8.88
Average..	25.0	52.6	24.8	35.3	148	92.0	1,575	1,805	.87	8.82

Table 16.—*Metabolism of E. D. B. during grade walking in experiments without food. (Values per minute.)*—Continued.

Date.	Grade.	Distance.	Average respiration-rate.	Average pulmonary ventilation (reduced).	Average pulse-rate.	No. of steps.	Carbon dioxide.	Oxygen.	Respiratory quotient.	Heat (computed).
1916.	*p. ct.*	*meters.*		*liters.*			*c. c.*	*c. c.*		*cals.*
Feb. 4.......	......	60.8	24.1	39.0	147	100.5	1,801	1,954	0.92	9.67
	......	62.7	27.6	45.3	162	100.0	1,932	2,141	.90	10.54
	......	63.2	29.2	50.6	......	96.2	1,976	2,158	.92	10.68
Average..	25.0	62.2	27.0	45.0	155	98.9	1,903	2.084	.91	10.29
Feb. 5.......	......	68.0	26.6	44.2	......	105.4	1,963	2,189	.90	10.78
	......	72.1	26.2	52.7	169	103.0	2,184	2,385	.92	11.80
	......	73.0	27.4	50.3	170	105.8	2,153	2,391	.90	11.77
Average..	25.0	71.0	26.7	49.1	170.	104.7	2,100	2,322	.90	11.43
Feb. 7.......	......	74.7	26.5	56.2	......	111.8	2,370	2,506	.95	12.49
	......	76.5	28.1	59.1	176	107.5	2,436	2,592	.94	12.89
	......	76.4	27.1	57.9	175	108.6	2,373	2,489	.95	12.41
Average..	25.0	75.9	27.2	57.7	176	109.3	2,393	2,529	.95	12.61
Feb. 8.......	......	49.3	23.8	36.1	129	94.0	1,626	1,811	.90	8.92
	......	49.6	27.7	38.2	135	94.4	1,637	1,876	.87	9.17
	......	42.5	26.6	32.8	132	81.6	1,373	1,644	.83	7.95
	......	42.4	26.6	33.6	136	85.0	1,417	1,649	.86	8.04
Average..	30.0	46.0	26.2	35.2	133	88.8	1,513	1,745	.87	8.53
Feb. 9.......	......	48.8	26.0	36.7	134	97.4	1,646	1,838	.90	9.05
	......	50.2	29.2	40.0	142	98.2	1,743	1,967	.89	9.66
	......	57.3	27.2	44.2	159	100.0	1,966	2,203	.89	10.82
	......	57.9	27.4	44.8	163	96.0	1,964	2,198	.89	10.80
Average..	30.0	53.6	27.5	41.4	150	97.9	1,830	2,052	.89	10.08
Feb. 10......	......	60.5	28.9	48.6	152	102.2	2,062	2,197	.94	10.93
	......	62.6	28.0	52.9	167	104.8	2,211	2,344	.94	11.66
Average..	30.0	61.6	28.5	50.8	160	103.5	2,137	2,271	.94	11.29
Feb. 11......	......	69.4	28.5	58.6	171	106.5	2,485	2,615	.95	13.04
	......	69.1	27.6	58.4	174	108.8	2,462	2,597	.95	12.95
	......	69.9	27.5	57.2	175	113.2	2,461	2.629	.94	13.07
Average..	30.0	69.5	27.9	58.1	173	109.5	2,469	2,614	.94	13.00
Feb. 12......	......	68.3	27.6	53.7	152	120.3	2,312	2,455	.94	12.21
	......	74.6	29.1	65.5	173	116.3	2,629	2,770	.95	13.81
Average..	30.0	71.5	28.4	59.6	163	118.3	2,471	2,613	.95	13.03
Feb. 14......	......	67.8	27.2	52.2	159	110.8	2,269	2,452	.93	12.16
	......	68.8	28.4	56.8	172	108.0	2,353	2,510	.94	12.48
Average..	30.0	68.3	27.8	54.5	166	109.4	2,311	2,481	.93	12.31

Table 16.—*Metabolism of E. D. B. during grade walking in experiments without food. (Values per minute.)*—Continued.

Date.	Grade.	Distance.	Average respiration-rate.	Average pulmonary ventilation (reduced).	Average pulse-rate.	No. of steps.	Carbon dioxide.	Oxygen.	Respiratory quotient.	Heat (computed).
1916.	*p. ct.*	*meters.*		*liters.*			*c. c.*	*c. c.*		*cals.*
Feb. 15......	......	43.1	26.0	39.2	135	98.8	1,687	1,926	0.88	9.44
	......	45.7	28.1	40.5	145	101.0	1,747	2,048	.85	9.96
	......	46.2	29.1	41.7	155	88.3	1,761	2,047	.86	9.98
Average..	35.0	45.0	27.7	40.5	145	96.0	1.732	2,007	.86	9.78
Feb. 16......	......	57.7	28.5	53.7	168	107.7	2,300	2,574	.89	12.64
	......	58.5	31.1	56.8	176	106.3	2,315	2,524	.92	12.49
	......	56.6	29.1	53.0	178	96.8	2,185	2,386	.92	11.81
Average..	35.0	57.6	29.6	54.5	174	103.6	2,267	2,495	.91	12.32
Feb. 17......	......	62.3	28.1	61.5	174	104.8	2,534	2,723	.93	13.51
	......	62.5	30.0	62.0	180	101.0	2,479	2,726	.91	13.46
Average..	35.0	62.4	29.1	61.8	177	102.9	2,507	2,725	.92	13.48
Feb. 18......	......	46.1	28.5	45.2	148	91.3	2,013	2,214	.91	10.93
	......	50.6	29.4	50.9	161	91.0	2,178	2,375	.92	11.75
	......	51.8	30.5	59.3	174	87.3	2,356	2,505	.94	12.46
Average..	40.0	49.5	29.5	51.8	161	89.9	2,182	2,365	.92	11.70
Feb. 19......	......	53.7	29.5	57.3	156	102.6	2,385	2,573	.93	12.76
	......	54.3	32.8	64.3	168	98.0	2,500	2,659	.94	13.22
	......	54.0	31.3	63.7	169	100.0	2,468	2,562	.96	12.80
Average..	40.0	54.0	31.2	61.8	164	100.2	2,451	2,598	.94	12.92
Feb. 21......	......	57.2	31.1	71.1	177	101.5	2,656	2,766	.96	13.82
	......	57.2	31.1	71.5	177	103.3	2,667	2,771	.96	13.85
	......	57.0	32.3	73.3	179	98.5	2,671	2,728	.98	13.70
Average..	40.0	57.1	31.5	72.0	178	101.1	2,665	2,755	.97	13.80
Feb. 22......	......	64.9	36.1	84.6	186	102.5	3,004	3,104	.97	15.55
	......	65.4	33.8	84.4	186	104.3	3,030	3,159	.96	15.79
Average..	40.0	65.2	35.0	84.5	186	103.4	3,017	3,132	.96	15.65
Feb. 23......	......	40.6	31.2	55.1	161	95.7	2,183	2,446	.89	12.01
	......	41.8	29.1	53.2	164	98.6	2,234	2,390	.93	11.85
	......	44.1	31.8	59.9	170	100.0	2,423	2,519	.96	12.59
Average..	45.0	42.2	30.7	56.1	165	98.1	2,280	2,452	.93	12.16
Feb. 24......	......	42.8	31.0	61.4	169	95.8	2,315	2,421	.96	12.10
	......	42.1	31.1	62.9	173	89.0	2,242	2,322	.97	11.63
Average..	45.0	42.5	31.1	62·2	171	92.4	2,279	2,372	.96	11.85

TABLE 16.—*Metabolism of E. D. B. during grade walking in experiments without food.* (*Values per minute.*)—Continued.

Date.	Grade.	Distance.	Average respiration-rate.	Average pulmonary ventilation (reduced).	Average pulse-rate.	No. of steps.	Carbon dioxide.	Oxygen.	Respiratory quotient.	Heat (computed).
1916.	*p. ct.*	*meters.*		*liters.*			*c. c.*	*c. c.*		*cals.*
Feb. 25	......	60.7	27.2	45.6	139	103.2	2,041	2,247	0.91	11.09
	......	60.9	30.2	49.6	144	103.2	2,123	2,314	.92	11.45
Average	30.0	60.8	28.7	47.6	142	103.2	2,082	2,281	.91	11.26
Feb. 26	......	68.6	28.4	50.9	148	103.2	2,307	2,509	.92	12.41
	......	70.1	32.0	58.3	158	105.2	2,467	2,674	.92	13.23
Average	30.0	69.4	30.2	54.6	153	104.2	2,387	2,592	.92	12.83
Feb. 28	......	66.7	28,0	52.0	149	107.6	2,302	2,443	.94	12.15
	......	67.1	32.4	57.9	150	107.2	2,446	2,573	.95	12.83
Average	30.0	66.9	30.2	55.0	150	107.4	2,374	2,508	.95	12.50
Feb. 29	......	68.4	31.2	54.1	147	105.2	2,232	2,441	.91	12.05
	......	68.5	33.0	58.8	158	102.8	2,336	2,540	.92	12.57
Average	30.0	68.5	32.1	56.5	153	104.0	2,284	2,491	.92	12.33
Mar. 4	......	49.1	27.6	42.2	131	....	1,621	1,764	.92	8.73
	......	48.6	30.8	44.4	137	....	1,624	1,829	.89	8.98
	......	47.2	29.8	42.9	137	....	1,552	1,751	.89	8.60
	......	49.1	27.8	43.4	143	....	1,625	1,914	.85	9.31
Average	30.0	48.5	29.0	43.2	137	....	1,606	1,815	.88	8.89
Mar. 6	......	51.1	27.1	45.2	128	....	1,763	1,923	.92	9.52
	......	52.2	29.7	48.0	138	....	1,783	2,013	.89	9.89
	......	52.5	27.9	46.9	142	....	1,800	2,044	.88	10.02
	......	53.0	30.0	48.1	150	....	1,795	2,015	.89	9.90
Average	30.0	52.2	28.7	47.1	140	....	1,785	1,999	.89	9.82
Mar. 7	......	51.0	28.2	44.2	132	....	1,774	1,909	.93	9.47
	......	51.1	28.3	44.0	143	....	1,682	1,942	.87	9.49
Average	30.0	51.1	28.3	44.1	138	....	1,728	1,926	.90	9.48
Mar. 8	......	51.2	28.1	46.7	139	....	1,761	1,891	.93	9.38
	......	51.2	29.7	47.2	143	....	1,735	1,942	.89	9.54
	......	51.3	29.8	49.9	150	....	1,807	1,961	.92	9.70
	......	52.3	30.8	50.8	154	....	1,766	2,073	.85	10.08
	......	51.5	28.7	48.5	152	....	1,769	2,011	.88	9.85
	......	51.7	29.5	47.9	160	....	1,723	2,043	.84	9.91
Average	30.0	51.5	29.4	48.5	150	....	1,760	1,987	.89	9.76
Mar. 23	......	62.5	23.5	22.3	101	....	937	1,127	.83	5.45
	......	61.9	24.3	23.1	104	....	955	1,089	.88	5.34
Average	10.0	62.2	23.9	22.7	103	....	946	1,108	.85	5.39

TABLE 16.—*Metabolism of E. D. B. during grade walking in experiments without food. (Values per minute.)*—Continued.

Date.	Grade.	Distance.	Average respiration-rate.	Average pulmonary ventilation (reduced).	Aver age pulse-rate.	No. of steps.	Carbon dioxide.	Oxygen.	Respiratory quotient.	Heat (computed).
1916.	*p. ct.*	*meters.*		*liters.*			*c. c.*	*c. c.*		*cals.*
Mar. 24	......	57.1	22.6	20.9	96	....	862	1,010	0.85	4.91
	......	56.7	23.4	20.3	102	....	847	996	.85	4.84
Average	8.9	56.9	23.0	20.6	99	....	855	1,003	.85	4.88
Apr. 6	......	46.3	21.7	20.8	99	....	770	908	.85	4.42
	......	47.4	21.2	19.1	101	....	784	904	.87	4.42
	......	47.3	21.3	18.7	104	....	773	907	.85	4.41
Average	10.0	47.0	21.4	19.5	101	....	776	906	.86	4.42
Apr. 7	......	45.6	21.7	19.2	90	....	757	906	.83	4.38
	......	46.5	21.3	19.5	99	....	767	909	.84	4.41
	......	47.2	21.5	19.2	102	....	773	911	.85	4.43
Average	10.0	46.4	21.5	19.3	97	....	766	909	.84	4.41
Apr. 8	......	35.2	20.0	17.2	90	....	681	795	.86	3.88
	......	36.2	20.4	17.8	95	....	700	777	.90	3.83
	......	36.0	21.2	17.3	94	....	679	781	.87	3.82
Average	10.0	35.8	20.5	17.4	93	....	687	784	.88	3.84
Apr. 14	......	40.5	21.6	18.3	85	....	559	667	.84	3.23
	......	40.8	21.6	18.3	88	....	552	645	.86	3.14
	......	39.8	22.0	18.2	......	....	536	624	.86	3.04
Average	5.0	40.4	21.7	18.3	87	....	549	645	.85	3.14
Apr. 15	......	39.6	20.9	17.1	80	....	476	543	.88	2.66
	......	40.1	21.7	16.9	84	....	458	530	.86	2.58
	......	39.5	21.9	16.9	90	....	453	518	.88	2.54
Average	2.4	39.7	21.5	17.0	85	....	462	530	.87	2.59

TABLE 16*a*.—*Average body-temperature and blood-pressure of E. D. B. during grade walking in experiments without food. (Values per minute.)*

Date.	Average body-temperature.	Date.	Average body-temperature.	Date.	Average body-temperature.
1916.	°*C.*	1916.	°*C.*	1916.	°*C.*
Jan. 5	38.39	Feb. 3	37.54	Feb. 5	37.44
	38.63		38.03		37.78
			38.33		37.84
Average	38.51	Average	37.97	Average	37.69
Feb. 2	37.19	Feb. 4	37.50	Feb. 7	37.61
	37.53		38.31		37.89
	37.75		38.79		37.66
Average	37.49	Average	38.20	Average	37.72

TABLE 16*a*.—*Average body-temperature and blood-pressure of E. D. B. during grade walking in experiments without food.* (*Values per minute.*)—Continued.

Date.	Average body-temperature.	Blood-pressure.
1916.	° *C.*	*mm.*
Feb. 8	36.97	
	37.93	
	38.24	
	38.31	
Average	37.86	
Feb. 9	37.77	
	38.37	
	38.76	
	38.89	
Average	38.45	
Feb. 11	38.00	
	38.25	
	37.97	
Average	38.07	
Feb. 12	37.37	
	38.13	
Average	37.75	
Feb. 14	37.49	
	38.47	
Average	37.98	
Feb. 15	37.65	
	38.47	
	38.74	
Average	38.29	
Feb. 16	37.76	
	38.47	
	38.59	
Average	38.27	
Feb. 17	37.68	
	38.48	
Average	38.08	
Feb. 18	37.73	
	38.59	
	39.03	
Average	38.45	
Feb. 19	36.95	
	37.97	
	38.33	
Average	37.75	
Feb. 21	37.72	
	38.05	
	38.20	
Average	37.99	
Feb. 22	38.29	
	....	
Average	38.29	
Feb. 23	38.11	
	38.33	
	38.33	
Average	38.26	
Feb. 24	37.92	
	38.50	
Average	38.21	
Feb. 25	37.31	
	38.14	
Average	37.73	
Feb. 26	37.25	
	37.97	
Average	37.61	
Feb. 28	37.11	
	....	
Average	37.11	
Feb. 29	36.98	
	37.89	
Average	37.44	
Mar. 4	37.23	
	37.70	
	36.70	
	36.68	
Average	37.08	
Mar. 6	37.27	
	38.01	
	37.56	
	38.12	
Average	37.74	
Mar. 7	37.55	....
	37.91	....
Average	37.75	....
Mar. 8	37.57	....
	38.26	....
	37.67	....
	38.24	....
	37.90	....
	38.39	.....
Average	38.01	....
Mar. 23	37.53	119
	37.62	116
Average	37.58	118
Mar. 24	37.74	126
	37.86	127
Average	37.80	127
Apr. 6	37.25	122
	37.53	128
	37.53	128
Average	37.44	126
Apr. 7	36.66	129
	37.17	130
	37.15	131
Average	36.99	130
Apr. 8	36.90	137
	37.09	138
	37.22	141
Average	37.07	139
Apr. 14	37.06	128
	37.41	128
	37.30	129
Average	37.26	128
Apr. 15	37.00	127
	37.28	129
	37.34	127
Average	37.21	128

DISCUSSION OF RESULTS.

The data given in the preceding section will be discussed in the general order of standing, horizontal-walking, and grade-walking experiments, considering first in each case the gaseous metabolism and the heat-output, then the physiological effects of the work performed. For such discussion reference will be made to tables in the statistical section (see p. 42) from which, with few exceptions, material for the other tables has been drawn.

BASAL METABOLISM.

While the special topic of this report is not basal metabolism, basal values were obtained for all of our subjects, usually by other members of the Laboratory staff, in experiments carried out for an entirely different purpose. Ordinarily these values were determined with a respiratory-valve apparatus or the universal respiration apparatus, and not infrequently with the clinical respiration apparatus.[1] Many observations were made in the comparison of the several methods, particularly during the development of the clinical respiration apparatus. The conditions in all of the experiments were those required for basal values, namely, the subject was in the lying position, in a post-absorptive condition, and with the greatest possible degree of muscular repose. The values may thus be considered to be true basal values. The data for all of the subjects except E. L. F. have already been reported in abstract in the biometrical analysis of basal metabolism measurements by Harris and Benedict.[2]

The basal-metabolism measurements were not used in the present study, save for the purpose of comparing the metabolism of the subjects in the lying position with the values for their metabolism when they were standing, to determine the influence of the effort of standing. (See table 22, p. 101.) Since these measurements of the basal metabolism were most carefully made, they should be recorded here, but the average results only are reported. (See table 17.)

In considering the values in table 17, it is obvious that the only results which contribute to the comparison of individuals with each other are those which have been computed on the basis of unit of body-weight or body-surface, for the individuals studied had materially different body-weights. The respiratory quotients are, for the most part, considerably above the quotient normally ascribed to the average man, viz, 0.82, but nevertheless are within a reasonable range. The respiratory quotient of H. R. R. varied considerably in the individual experiments, ranging from 0.76 to 0.93. His average of 0.80 is lower than that for any other subject. Furthermore, it is clear that H. R. R.

---

[1] Benedict and Tompkins, Boston Med. and Surg. Journ., 1916, **174**, pp. 857, 898, and 939.

[2] Harris and Benedict, Carnegie Inst. Wash. Pub. No. 279, 1919, pp. 42 and 43. Only such of the data for A. J. O. and H. M. S. as were obtained at about the period of this research are used for comparison in this report. (See table 17.)

TABLE 17.—*Basal metabolism of subjects in lying position and without food. (Values per minute.)*[1]

	A. J. O.	H. R. R.	T. H. H.	W. K.	E. D. B.	J. H. G.	E. L. F.	H. M. S.	Average.
Age....................yrs....	30	19	29	29	23	20	23	48	....
Body-weight without clothing.....kg....	70.6	70.0	54.5	49.2	56.9	67.2	71.9	60.4	62.6
Height....................cm....	180	185	171	162	173	185	171	180	176
No. of experimental days..............	11	4	12	18	4	1	1	1	....
No. of experimental periods............	82	32	64	128	10	4	2	4	....
Period covered by experiments....days..	37	38	45	163	94	1	1	1	....
Carbon dioxide..................c. c...	212	215	181	159	183	204	208	172	192
Oxygen....................c. c....	247	269	207	187	215	247	238	196	226
Respiratory quotient..................	0.86	0.80	0.87	0.85	0.85	0.83	0.87	0.88	0.85
Pulse-rate.........................	59	73	59	57	58	68	65	64	63
Heat-output (computed)..........cals...	1.20	1.29	1.01	0.91	1.05	1.19	1.16	0.96	1.10
Heat-output per 24 hours:									
Total....................cals...	1,728	1,860	1,457	1,310	1,506	1,721	1,670	1,382	1,579
Per kg. of body-weight.......cals...	24.5	26.6	26.7	26.6	26.5	25.6	23.2	22.9	25.3
Per sq. meter of body-surface[2].cals...	919	964	894	868	896	911	918	776	893

---

[1] The values for all of the subjects but A. J. O., H. M. S., and E. L. F., have been taken from Harris and Benedict, Carnegie Inst. Wash. Pub. No. 279, 1919, pp. 42 and 43, table C. The number of experimental days differ in the two tables, as the figures in table C represent for these subjects the number of experiments, and on some days two experiments were made.

[2] The body-surface was obtained by the use of the Du Bois height-weight chart.

had a measurably higher pulse than any of the other men, a point which should be borne in mind in the later consideration of the results of the walking experiments.

The heat-output per 24 hours per kilogram of body-weight, in which an effort is made to equalize differences in body-weight, shows a range of 22.9 to 26.7 calories. This compares favorably with the 25.7 calories per kilogram of body-weight given by Harris and Benedict as an average value for 136 men.[1] The heat produced per square meter of body-surface, with the body-surface computed by the height-weight chart of the Du Boises, shows variations of considerable magnitude, ranging from 776 calories with H. M. S. to 964 calories with H. R. R., with an average of 893 calories. The average value given by Harris and Benedict for the 136 men previously referred to was 925 calories per square meter of body-surface. It is of considerable importance to note that with the group of men selected for use in treadmill experiments, and presumably in normal health, such wide variations appear in the heat-production per square meter of body-surface.

The difficulty in predicting the heat-production of an individual from either the surface area or the body-weight alone is clear from the values given in table 17. A further indication of the normality of our subjects may be found in a comparison of these basal measurements with values computed by means of the prediction formula of Harris and Benedict,[2] which is based upon the biometric analysis of values obtained for 136 normal men. This comparison is made in table 18.[3] With every individual the predicted heat-production is reasonably close to that determined, the widest deviation being with H. M. S., whose basal metabolism was 91 calories per 24 hours less than the predicted metabolism, or a difference of 6.2 per cent.

It should be brought out here that we are not dealing with a group of men of a pronouncedly athletic temperament. The only man who could logically be classed as an athlete was A. J. O., who was a semi-professional baseball player.[4] In an earlier study, in which the metabolism of athletes and normal individuals was compared,[5] the evidence was reasonably clear that athletes as a group show a higher metabolism than do normal individuals, although the original estimate of the influence of athletic build and habit upon the metabolism was somewhat reduced by a subsequent careful biometric analysis.[6] From the values given in table 18, it is evident that the agreement between the predicted and the determined heat-output is close enough to preclude the contention that the athletic habits of these individuals were sufficient for them to acquire strictly athletic characteristics. Almost no evidence of a consistently higher metabolism in the determined figures of this group may be seen, but two subjects showing plus values. While we are somewhat surprised that greater differences are not noted between the predicted and the determined metabolism, the results are perhaps to be expected when it is considered that these men were not primarily athletes. The usefulness of the Harris and Benedict formula for predicting the metabolism with fairly homogeneous material is here demonstrated, and the results confirm the recent test of the formula in the prediction of the metabolism of a group of 12 normal men, when it was found that the average for the predicted total heat-output was within +1.1 per cent of the average measured value.[1]

---

[1] Harris and Benedict, Carnegie Inst. Wash. Pub. No. 279, 1919, p. 204.

[2] Harris and Benedict, *Ibid.*, p. 227.

[3] It should be stated that the subjects of this study on the effect of walking were, most of them, used for obtaining the data employed by Harris and Benedict. In other words, the predicted values given in table 18 are not independent of the derivation of the formula, but were a part of the results obtained for the group of 136 men from which the formula was computed.

[4] This subject was used by Benedict and Murschhauser (Carnegie Inst. Wash. Pub. No. 231, 1915), who report other data concerning him.

[5] Benedict and Smith, Journ. Biol. Chem., 1915, **20**, p. 342.

[6] Harris and Benedict, Carnegie Inst. Wash. Pub. No. 279, 1919, p. 245.

Table 18.—*Heat-production of subjects in lying position and without food, as computed from respiration experiments and as predicted by the use of the Harris and Benedict formula.*

Subject.	Heat per 24 hours.		Computed heat greater (+) or less (−) than predicted.	
	Computed from respiration experiments.	Predicted by use of Harris and Benedict formula.	Total difference.	Percentage difference.
	cals.	*cals.*	*cals.*	
A. J. O.	1,728	1,720	+ 8	+0.5
H. R. R.	1,860	1,826	+34	+1.9
T. H. H.	1,457	1,476	−19	−1.3
W. K.	1,310	1,358	−48	−3.5
E. D. B.	1,506	1,560	−54	−3.5
J. H. G.	1,721	1,781	−60	−3.4
E. L. F.	1,670	1,735	−65	−3.7
H. M. S.	1,382	1,473	−91	−6.2
Average	1,579	1,616	−37	−2.4

We believe that the results in tables 17 and 18 show that we are dealing with normal individuals, and that these basal-metabolism values may be considered as of physiological importance and their use in subsequent comparisons with the results of other experiments is entirely justifiable. It is to be regretted that a more extensive analysis of basal measurements for these subjects, covering a greater length of time and perhaps for different seasons of the year, can not be made here, although other basal data for some of the subjects have actually been collected. Such an analysis has recently been made by Dr. J. Arthur Harris.[2]

---

[1] Benedict, Miles, Roth, and Smith, Carnegie Inst. Wash. Pub. No. 280, 1919, p. 521.

[2] Harris and Benedict, Journ. Biol. Chem., 1921, **46**, p. 257.

EXPERIMENTS WITH SUBJECT STANDING.

Metabolism During Standing.

As the metabolism during standing has been generally taken as a basis for comparison in computing the increments due to the muscular effort of walking, determinations of the metabolism of the subjects under these conditions were made from time to time as the research progressed. When superimposed factors affecting metabolism but little, such as the ingestion of food, body-posture, etc., are to be studied, basal experiments are needed with each comparison, but in walking and other muscular-work experiments, when the superimposed factor results in a large increase in the metabolism, an average base-line, either for the lying metabolism or the standing metabolism, may properly be used, as slight differences from day to day in the basal metabolism are not relatively important. Thus, for W. K. and E. D. B., metabolism experiments with the subject standing were made on 14 and 71 days, respectively, these experiments varying in length from one to six periods each. The daily average values were used for computing the increase in the metabolism during the walking experiments. Such experiments made at intervals during a period of several months permitted the observation of any changes in the factors recorded which might be attributed to practice or to seasonal causes. The smaller amount of data obtained with the other subjects is used more especially for comparison with these values for W. K. and E. D. B.

Carbon-Dioxide Elimination.

The carbon dioxide eliminated per minute by the subjects while standing is given in tables 3 to 7 for each period, together with the daily averages. (See pp. 43 to 55.) The values for H. R. R. for March 20, 1915, which was the first day of experimenting with this subject, are so much larger than those of the other days that they have not been included in the general average for this subject. The average for the carbon dioxide eliminated per minute in the two days remaining is 216 c. c.

With W. K., standing experiments were made on 14 days, the carbon-dioxide elimination varying from an average of 174 c. c. per minute on March 11 to 200 c. c. per minute on March 13, 1915. The average for the 14 days is 186 c. c. per minute.

In the 71 days on which standing experiments were made with E. D. B., there were 10 days in February 1916 when the experiment had but one period, and on 3 days in the same month and 1 each in December 1915 and April 1916 there were but two periods. On the other experimental days there were three or more periods. The daily average for the 71 days ranged from a minimum of 181 c. c. per minute on October 27, 1915, to a maximum of 225 c. c. on February 21, 1916. The maximum of 225 c. c. per minute on February 21, 1916, is the maximum of a group of high values for carbon-dioxide elimination after several days of somewhat strenuous exercise in walking at 40 per cent grade. Moreover, it was obtained in a single period, and therefore may not fairly represent the daily average, but has been included with the data for the other days in averaging.

The daily average for the 71 days of experimenting with this subject is 199 c. c. per minute. A direct comparison of the carbon-dioxide values from day to day can only be made with due regard to changes in body-weight. These actually did take place, but the average value for the whole series, i. e., 199 c. c., is to be considered as referable to a body-weight varying only from 57 to 59 kg.

Oxygen Consumption.

As with the carbon-dioxide elimination, the apparently abnormal values for H. R. R. obtained on the first day of experimenting with him are not included in the daily average for this subject. The average for the two days remaining is 281 c. c. per minute. The daily average oxygen consumption for W. K. varied from 212 c. c. on 4 days to 257 c. c. per minute on March 17, 1915. The average was 228 c. c. for the 14 days when standing experiments were made. In the 71 days with E. D. B., the average oxygen consumption for the day was 240 c. c. per minute, with range from 206 c. c. on November 18, 1915, to 288 c. c. on February 23, 1916. The daily averages for this subject show two distinct periods, the values being lower from October to December, and considerably higher after the Christmas recess and during the spring months. During this period E. D. B. gained in body-weight, and as these figures represent the total oxygen consumption, it would appear that his standing metabolism was increased. When, however, allowance is made for this increase in weight, as is done in table 21 (see p. 99), it is seen that his metabolism per kilogram of body-weight is but slightly greater.

Respiratory Quotient.

The average respiratory quotients for the subjects standing, as given in tables 3 to 7, are what would be expected for men of this class. The relatively low average value of 0.77 for H. R. R. may possibly be explained by the fact that this man was earning his way through college and acted as a waiter in a college commons. The report of the meals taken previous to each experiment showed that he was living very frugally.

The variations in the respiratory quotient from period to period are, on the whole, not excessive. While there were some discrepancies, these might be expected with so large a number of determinations, and it is believed that they are eliminated in averaging. The data show a tendency for the quotients in the first periods of the day to run a little higher, possibly, than in the succeeding periods, although the number of such periods is not sufficient to make any deduction therefrom justifiable. The respiratory quotients for the 71 days with E. D. B. have an average daily value of 0.84 in the period from October 4 to December 22, 1915, as compared with 0.82 during the period from March 1 to April 15, 1916. On February 23, the day following his most severe walking test with an oxygen consumption of 3,132 c. c. per minute (see table 16, p. 86), there was a marked fall in his respiratory quotient, which may have been due to the after-effects of the vigorous exercise of the preceding day. Zuntz and Schumburg[1] and Durig[2] have noted that the respiratory quotients tend to fall during periods of exercise and that this effect is also apparent on the following day. The respiratory quotient of February 23 is, however, based on but one period. (See table 6, page 50.)

The average respiratory quotients obtained with these five men in the standing positions are as follows: A. J. O., 0.84; H. R. R., 0.77; T. H. H., 0.86; W. K., 0.82; E. D. B., 0.83; and for the three members of the Laboratory staff, J. H. G., 0.79; E. L. F., 0.85; and H. M. S., 0.78. Using the results obtained with these eight subjects, covering measurements on 3 to 71 days, and in most instances with three periods each day, we may conclude that the average respiratory quotient of a normal man in the standing position and the post-absorptive condition is 0.82. This value is slightly lower than that found in measurements made (usually on other days) with these subjects in the lying position, both for the average value as well as in all but one of the individual cases (see table 17, p. 91), and a little higher than the respiratory quotient obtained at the Nutrition Laboratory with normal men.[3]

HEAT-OUTPUT.

The heat-output of these standing subjects, as calculated from the calorific value of the oxygen consumed and the respiratory quotient, is also given in tables 3 to 7, and represents the energy requirement of the subjects when standing quietly in the post-absorptive condition. This value has been used as a base-line for calculating the increase in the energy requirement due to the muscular effort of walking.

The values of W. K. show considerable daily variation, but indicate no regular change. With E. D. B. there is an apparent seasonal change represented by the periods extending from October 4 to December 22, 1915, when the total heat-output per minute was 1.10 calories, and from March 1 to April 15, 1916, when the average was 1.18 calories.

---

[1] Zuntz and Schumburg, Physiologie des Marsches, Berlin, 1901, p. 259, also table 23, p. 258.

[2] Durig, Archiv f. d. ges. Physiol., 1906, **113**, p. 263.

[3] Benedict, Miles, Roth, and Smith, Carnegie Inst. Wash. Pub. No. 280, 1919, p. 532.

During this time, however, E. D. B. showed a gain in body-weight of 3.2 kg. (see table 21), so that the increase in the heat-output was largely due to this factor. With an average body-weight of 56.2 kg. during the period from October 4 to December 22, 1915, his metabolism was 28.2 calories per kilogram of body-weight per 24 hours, while for the period from March 1 to April 15, 1916, with an average body-weight of 59.4 kg., his metabolism was 28.7 calories per kilogram of body-weight per 24 hours. When the data for the eight subjects are computed on the basis of body-weight, they show an average energy requirement per minute per kilogram of body-weight of 0.0197 calorie. (See table 19.) This is equivalent to 1.18 calories per kilogram per hour as compared with 1.22 calories per kilogram per hour reported by Benedict, Miles, Roth, and Smith[1] for a group of ten normal men in standing experiments.

Table 19.—*Average heat-output of subjects standing in the post-absorptive condition.*

Subject.	No. of days.	Body-weight without clothing.	Heat-output per minute.	Heat-output per kg. of body-weight.	
				Per min.	Per 24 hrs.
		kg.	*cals.*	*cal.*	*cals.*
A. J. O.	3	69.5	1.31	0.0188	27.1
H. R. R.	2	70.0	1.34	.0191	27.5
T. H. H.	3	54.5	1.11	.0204	29.4
W. K.	14	49.2	1.10	.0223	32.1
E. D. B.	71	57.0	1.16	.0203	29.2
E. L. F.	3	70.4	1.29	.0183	26.4
J. H. G.	3	68.0	1.34	.0197	28.4
H. M. S.	2	60.4	1.13	.0187	26.9
Average	....	....	1.22	.0197	28.4

General Summary of Measurements of Metabolism During Standing.

In table 20 a summary is given of the extremes and average values obtained in the gaseous-metabolism measurements in the standing experiments with W. K. and E. D. B., with whom the larger part of the data was collected. For comparison, average values and ranges are given for other measurements obtained and discussed in later sections of this monograph. (See p. 101.) These figures show what may be the ranges and average values for the various factors for men of this age when they are standing quietly in the post-absorptive condition. The data for W. K. are, for the most part, for 14 days, covering a period from February to June 1915, and for E. D. B. for 71 days from October 1915 to April 1916.

---

[1] Benedict, Miles, Roth, and Smith, Carnegie Inst. Wash. Pub. No. 280, 1919, p. 528.

The metabolism measurements for E. D. B. have been plotted in figure 9, which shows the average daily values on the dates that standing experiments were made during the period from October 1915 to April 1916. It is seen from this chart that between December 22 and 31, 1915, the carbon-dioxide output and oxygen consumption, as well as the heat-output, rose to a markedly higher level, the values being considerably lower between October and December than those obtained during the remainder of the winter and in the spring months. This may be accounted for in part by an increase in the body-weight of approximately 7 per cent, but this alone is not sufficient to account for all the increase. The technique of the experiments had not been altered, but the pulse-rate showed a like acceleration at this time, thus indicating a stimulated body condition from some cause. This difference in the metabolism between the early and late experiments is shown in table 21, in which the averages of the daily values for the metabolism from October 4 to December 22, 1915, are compared with those for the period from March 1 to April 15, 1916. These values have also been computed on the basis of per kilogram of body-weight, and show an increase in the total heat produced per kilogram of body-weight of 1.5 per cent. Since only the increments in metabolism are

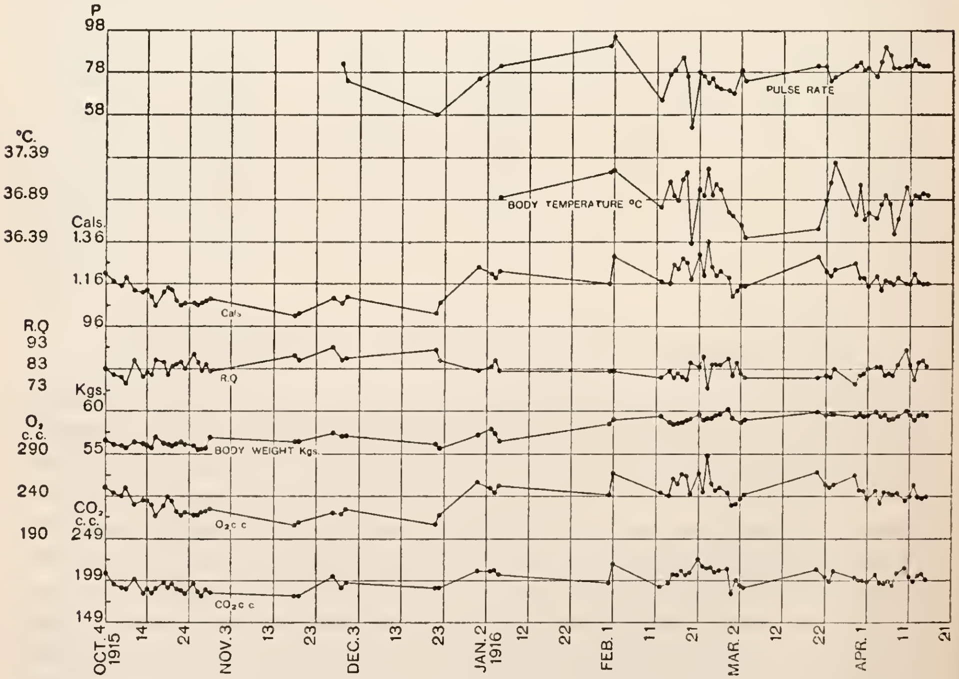

FIG. 9.—Metabolism of E. D. B. in standing experiments without food. (Values per minute.)

considered for the most part in this study of walking, it has not seemed necessary to duplicate all the calculations on the per kilogram of body-weight basis.

Table 20.—*Average results for various measurements in standing experiments with W. K. and E. D. B.*

Measurement.	W. K.		E. D. B.	
	Average.	Range.	Average.	Range.
Carbon dioxide..........c. c. ..	186	174 to 200	199	181 to 225
Oxygen................c. c. ..	228	212 to 257	240	206 to 288
Respiratory quotient...........	0.82	0.74 to 0.91	0.83	0.74 to 0.93
Heat-output.............cals...	1.10	1.03 to 1.21	1.16	1.01 to 1.36
Body-temperature....... °C....	....	....	36.89	36.36 to 37.33
Respiration-rate...............	21.1	18.1 to 24.9	15.4	12.3 to 16.7
Pulmonary ventilation...liters..	[1]6.45	5.60 to [1]7.4	9.1	6.2 to 10.1
Pulse-rate.....................	79	74 to 85	78	52 to 95
Blood-pressure...........mm...	....	....	116.5	109 to 125

[1] Does not include March 18 and June 2 to 14, 1915.

Table 21.—*Comparison of metabolism of E. D. B. in standing experiments, in periods October 4 to December 22, 1915, and March 1 to April 15, 1916. (Values per minute.)*

Measurement.	Oct. 4 to Dec. 22, 1915.	Mar. 1 to Apr. 15, 1916.
Body-weight without clothing.........kg....	56.2	59.4
Total carbon dioxide.................c. c. ..	190	201
Total oxygen.........................c. c...	226	245
Respiratory quotient......................	0.84	0.82
Total heat (computed)..............cals...	1.10	1.18
Per kilogrammeter of body-weight:		
Carbon dioxide.................c. c....	3.38	3.38
Oxygen.......................c. c. ..	4.02	4.12
Heat per minute...............cals...	0.0196	0.0199
Heat per hour..................cals...	1.176	1.194

Lusk[1] reports that a dog which had been allowed to run in the country during the summer months showed a metabolism 16 per cent higher than when confined in the laboratory. Benedict, Miles, Roth, and Smith[2] also noted for a group of 12 men (Squad B) an apparent seasonal change from 1.10 calories to 0.98 calorie per kilogram per hour in the basal metabolism between October and January. A seasonal change in the metabolism is therefore not to be regarded as unusual, and E. D. B. may have found the regular life and the exercise of the morning walks in the laboratory, with good food and freedom in the afternoon, of such benefit that it resulted not only in an increase in body-weight but in a generally improved physical condition.

---

[1] Lusk, Journ. Biol. Chem., 1915, **20**, p. 564.

[2] Benedict, Miles, Roth, and Smith, Carnegie Inst. Wash. Pub. No. 280, 1919, p. 523; see, also, footnote, p. 500.

The increase in the pulse-rate referred to, which was coincidental with the higher level of the heat-output, is readily seen in figure 9, in which the pulse-rate is plotted for 43 days. A comparison of the general trends of the curves for pulse-rate and heat-output shows agreement, the pulse tending to increase or decrease in correspondence with the heat. This seems to confirm the statement of Benedict and Cathcart[1] that for the same individual in normal health and in the post-absorptive condition, an increased metabolism is accompanied by an increased pulse-rate. There is, however, a marked exception to this agreement on February 23, when the heat-output is higher than that of the preceding days and the pulse-rate shows a slight fall. As was stated in discussing the oxygen consumption of E. D. B. for this day, the severest walking test for this subject was on the day preceding this lowered pulse-rate. During this test his oxygen consumption rose to 3,132 c. c. per minute and he was exhausted at the end of the walking periods. It is not impossible that the effect upon the oxygen consumption was also present on February 23, whereas the pulse-rate had reached a more nearly normal basis.

Comparison of Metabolism for Lying and Standing Positions.

Strictly speaking, in studying the effect of a factor showing such small differences in the metabolism as is produced by the change in position from standing to lying, both lying and standing experiments should be made on the same day. Since this difference was a subsidiary problem, and the time could not be spared for it in connection with the walking tests, we must use average values for comparison. The metabolism of these men in the standing position may be compared to their basal metabolism recorded for the lying position in table 17, page 91. This comparison has been made in table 22. The greatest increase in the total heat-output due to the change in position is found with W. K. (21 per cent) and the smallest increase with H. R. R. (4 per cent). The average for all the subjects is 12 per cent. The low increase for H. R. R. can hardly be attributed to his basal results, for they represent an average of 32 experimental periods and a heat-output per kilogram of body-weight per 24 hours of 26.6 calories, which is of the same order as that given for the other subjects in table 17; nor are the standing values given in table 19 unduly low, for the average total heat-output of H. R. R. while standing is 1.34 calories per minute, or 27.5 calories per 24 hours per kilogram of body-weight. The high percentage increase over lying of W. K. is due to his relatively high standing value,

---

[1] Benedict and Cathcart, Carnegie Inst. Wash. Pub. No. 187, 1913, p. 154.

TABLE 22.—*Comparison of the total metabolism of subjects in lying and standing positions, with percentage increase for the standing position.* (*Values per minute.*)

Subject.	Carbon dioxide.		Oxygen.		Respiratory quotient.		Heat-output.		Increase in standing over lying.	
	Lying.	Standing.	Lying.	Standing.	Lying.	Standing.	Lying.	Standing.	Oxygen.	Heat.
	c. c.	*c. c.*	*c. c.*	*c. c.*			*cals.*	*cals.*	*p. ct.*	*p. ct.*
A. J. O.	212	226	247	271	0.86	0.84	1.20	1.31	10	9
H. R. R.	215	216	269	281	.80	.77	1.29	1.34	5	4
T. H. H.	181	196	207	227	.87	.87	1.01	1.11	10	10
W. K.	159	194	187	228	.85	.82	.91	1.10	22	21
E. D. B.	183	199	215	240	.85	.83	1.05	1.16	12	11
J. H. G.	204	221	247	279	.83	.79	1.19	1.34	13	13
E. L. F.	208	224	238	265	.87	.85	1.16	1.29	11	11
H. M. S.	172	184	196	236	.88	.78	.96	1.13	20	18
Average	192	208	226	253	.85	.82	1.10	1.22	13	12

which is 1.10 calories per minute, or 32.1 calories per 24 hours per kilogram of body-weight (see table 19) rather than to a low value for his metabolism in the lying position. This high percentage increase finds support in the value of 18 per cent for H. M. S., although the experiments with this subject were few in number, being only one for the lying position and two for the standing. The results in table 22 would seem to indicate that the effort of standing was marked by a decided difference in the energy required for different individuals, with an average increase of 10 to 12 per cent.

PHYSIOLOGICAL EFFECTS OF STANDING.

In addition to measurements of the metabolism with the subjects standing, records were also obtained of the respiration-rate, pulmonary ventilation, and pulse-rate by the methods previously outlined. In many of the experiments with E. D. B., records were also obtained of the body-temperature and the blood-pressure. The data are summarized in table 23 and given in detail in tables 3 to 7 (see pp. 43 to 55).

RESPIRATION-RATE WITH SUBJECT STANDING.

From tables 3 and 23 it is seen that the average daily respiration-rate for A. J. O. for the three days on which standing experiments were made was 21.8, but there are too few experiments to give evidence of any marked change in this factor. That the respiration-rate of A. J. O., as well as that of W. K., is higher than the rates of the other subjects should not be given undue weight.

With H. R. R. the respiration-rate on the first day of experimenting was much higher than on subsequent days, the average for the day

Table 23.—*Average results in various physiological observations with subjects standing.* (*Values per minute.*)

Subject.	No. of experiments.	Respiration-rate.	Ventilation of lungs.	Pulse-rate.
			liters.	
A. J. O.	3	21.8	7.8	....
H. R. R.	2	15.5	7.0	93
T. H. H.	3	12.9	6.5	96
W. K.	14	21.1	6.5	79
E. D. B[1]	71	15.4	9.1	78
J. H. G.	3	16.3	10.6	110
E. L. F.	3	15.0	10.6	107
H. M. S.	2	16.9	10.0	92

[1] E. D. B., body-temperature (40 days), 36.89° C.; blood-pressure (20 days), 116.5 mm.

being 20.6. (See table 3, p. 43.) In the other standing experiments, the respiration-rate varied from 14.9 to 16.6, with averages on April 10 and 17, 1915, of approximately 15.5. Undoubtedly on the first day (March 20) the subject was under considerable mental excitement and the respiration-rate recorded for this day was probably not normal; it has therefore been omitted in calculating the average. The data in table 3 (p. 43) give no marked evidence of a change in the respiration-rate in any one direction from period to period or from day to day, though it might be said that there was a tendency for the respiration-rate to be lower during the later periods of the day.

The respiration-rate of T. H. H. shows a slight tendency to increase from period to period on the days when standing experiments were made with this subject. The daily average varied from 12.7 to 13.2, with a general average of 12.9 for the series.

The average respiration-rate for the day varied with W. K. from 18.1 on March 17 to 24.9 on March 12, 1915, with an average for the entire series of 21.1. (See table 5, p. 44.) There was no marked change one way or the other in the rate from period to period as the standing continued. It might be said that frequently the highest values were obtained during the first period of the several experiments. No tendency is shown towards a decided difference in the respiration-rates obtained in the early experiments in February and March and those recorded in the later experiments, the average for February and March being 21.1 and that for May and June 21.2.

E. D. B. had the lowest initial daily respiration-rate of any of the subjects. His average rate varied from 12.3 on October 4 (the first record) to 16.7 on November 29, 1915. An inspection of table 6 shows that there is a slight tendency for the respiration-rate to increase in the succeeding periods of the forenoon. This increase is not large and but rarely amounts to a full respiration per minute. There are many instances, however, in which the rate is slower in the latter part of the forenoon. With this subject there also seems to be an increase in the respiration-rates from the early days of October up to the latter part of November. Thus, the average respiration-rate for the seven days from October 4 to 14, inclusive, is 13.8, and the average rate in the standing periods from November 18 to December 22, inclusive, is 15.1, while the average of the respiration-rates between April 8 and 15, inclusive, is 15.4. These figures show that there was undoubtedly an increase in the rate from the beginning of the study in October up to the latter part of November, while but little change took place subsequent to that time. The average respiration-rate for the whole series with E. D. B. is 15.4.

As previously stated, during the period that E. D. B. was incapacitated on account of his lame ankle, three of the assistants served as volunteer subjects. The respiration-rates obtained with J. H. G., E. L. F., and H. M. S. are given for comparison with those for the regular subjects. There is considerable difference between the respiration-rate of E. L. F. for January 22 and that of January 24, 1916. This man was perfectly familiar with the routine of respiration experiments as carried out in the Nutrition Laboratory, although January 21 was the first time he had ever been the subject of a treadmill experiment. The protocol for January 24 notes that during the second and third standing periods he showed "considerable fatigue" at the end of each period and that it required an "effort to hold out to the end of the period." The statement is also made: "Subject sweating considerably at the end of the period." It is evident that this man was not in the best of condition on that day, although he went through the walking periods subsequently without effort or complaint. The high respiration-rate of 17.5 for January 24 is undoubtedly due, in part at least, to the physical condition of the subject.

Pulmonary Ventilation with Subject Standing.

The data showing the lung ventilation of the different subjects during the standing experiments are collected in tables 3 to 7 and represent the average number of liters of air entering the lungs per minute, reduced to standard conditions of temperature and pressure, i. e., 0° C. and 760 mm. The daily averages are later used for comparison with the increased ventilation requirements during walking. The general averages for the subjects are summarized in table 23.

A. J. O. showed a ventilation ranging in the different periods from 7.4 to 8.3 liters per minute, with an average value of 7.8 liters per minute for the three days represented. With this subject there appeared to be a tendency for the average ventilation to increase from day to day.

With H. R. R. the ventilation per minute ranged from 12.1 liters for the first period on March 20 to 6.5 liters for the third period on April 17. The average for the day ranged from 11.7 liters on March 20 to 6.7 liters on April 17. This wide variation is undoubtedly due to a psychical disturbance on March 20, when H. R. R. took his first test. Pulmonary ventilation may not be without value in estimating the mental repose of a subject. In this connection we should also note the other factors measured, such as pulse-rate and oxygen consumption, these being higher than on subsequent days. This day's results have been excluded from the average, although there is every reason to believe that they represent the pulmonary ventilation at the time of the experiment. The average ventilation of the lungs with this subject for the entire series of experiments is 8.5 liters per minute, if March 20 is included, and 7.0 liters without this day. The ventilation in the first period of each day is larger than the subsequent periods and the daily averages decreased as the experimenting continued.

The pulmonary ventilation of T. H. H. ranged from 5.0 to 7.5 liters per minute, with an average of 6.5 liters per minute for the three days. No tendency toward a uniform change in the ventilation from day to day or from period to period is apparent and his ventilation is, on the whole, fairly uniform.

The experiments with W. K. extended from February to June, 1915. The lowest pulmonary ventilation during this time appeared in the first period on March 11, with a value of 5.5 liters per minute, and the greatest lung ventilation per minute was in the second period on both June 2 and 3, i. e., 10.7 liters. The lowest daily average was 5.7 liters on March 17 and the greatest 10.6 liters on June 3. When we examine this series of figures, it is noted that the ventilation on March 18 and that on the dates subsequent to June 1 show marked increases. On March 18 the by-pass (see *B*, fig. 1, p. 19), deflecting the circulating air-current nearer to the mouthpiece, was inadvertently not turned, thus adding somewhat to the dead-space of the apparatus. It is probably due to this fact that the ventilation was increased from an average of 5.7 liters on the previous day to 9.0 liters per minute on March 18. The by-pass was installed in anticipation of a greater demand for ventilation during exercise and was not considered so essential for the standing experiments. As further evidence of the importance of its use, we have the experiments of June 2 to 14, in which the by-pass was purposely not used, these showing that the ventilation of the lungs is again very much higher. The average ventilation of the lungs of 6.5 liters for W. K. does not, therefore, include the data for March 18 and the observations from June 2 to June 14, when the by-pass was not used. If we omit these days from the discussion, we find that the daily average ventilation of W. K. ranged from 5.7 liters (the average for March 17) to 7.4 liters (the average for

March 13), with no tendency for the ventilation to change in any one direction as the season advanced in the period from February 26 to June 1. During this time the man was walking almost daily on the treadmill at considerable grades and speeds. On many days the ventilation in the first period of the day was greater than that in succeeding periods, but there are a sufficient number of exceptions to prevent the making of any categorical statement.

E. D. B. has the largest number of periods and days from which comparisons may be made. The pulmonary ventilation varied with this subject from 6.1 liters per minute in the first periods of November 18 and 19 to 10.3 liters per minute in the third period of December 31, while the daily average varied from 6.2 liters per minute on November 18 to 10.1 liters per minute on February 15. The figure for February 15 was, however, the record of but one period. The low averages of 6.2 liters for November 18 and of 6.3 liters on the day following are exceptional, as aside from these two days the lowest daily average is 8.0 liters on December 22. The figures for the lung ventilation on November 18 and 19 are, however, believed to be correct, as the tracings on the kymograph have been measured and agree with the record of the ventilation adder. They are accordingly included in the general average for the lung ventilation of E. D. B., which is 9.1 liters per minute.

The data for the ventilation of the lungs do not indicate that it was larger at any particular period of the day than at another. Though there are variations, they are no greater than might be expected and appear to be as much in one direction as in the other. On the whole, the ventilation seems to be fairly uniform for each day's series. If the daily average ventilation is compared by periods of 10 days or 2 weeks we have the following results for liters per minute:

Oct. 4 to 14.	Oct. 15 to 29.	Nov. 27 to Dec. 22.	Mar. 1 to 31.	Apr. 1 to 15.
8.6	9.3	9.0	9.2	9.2

The two exceptionally low values obtained on November 18 and 19, 1915, were omitted from these averages. It would appear from this grouping of the values that after the first 10 days the lung ventilation of the subject while standing did not materially alter as a result of his daily exercise in walking.

The lung ventilation of J. H. G. showed an increase for each succeeding period on the three days that he was a subject, with a variation in the daily average from 10.1 to 11.3 liters per minute and an average for the three days of 10.6 liters per minute. With E. L. F. the ventilation increased considerably on January 24 over that of the preceding days, the pulse-rate also showing an increase on that day; but this high value is included in the total average of 10.6 liters per minute for this subject. In the two days that H. M. S. served as subject, the ventilation varied from 9.9 to 10.3 liters per minute, with an average of 10 liters per minute.

In looking over the figures for pulmonary ventilation, it is evident that there is a possibility of considerable variation in this factor, not only from day to day but from period to period. This variation makes it difficult to state definitely whether or not training on the apparatus has any influence in the volume of air inhaled into the lungs. The most definite information on this point is found with E. D. B., with whom during the second fortnight there was an average increase of 0.7 liter over the ventilation in the preceding 10 days, while for the remainder of the season, a period of approximately 6 months, the difference was not more than 0.3 liter. The fact that the use of the by-pass was omitted in the later standing experiments with W. K. prevents any definite conclusion on this point from his data, while the experiments with the other subjects were too few to throw light on the point under discussion.

When the average pulmonary ventilation per minute of these men is compared on the basis of nude weight, it is found that the ventilation of the lungs is not directly conditioned by this factor. That a considerable variation in the ventilation per kilogram of body-weight is possible is seen by the comparison made in table 24. Subsequent research must take into consideration vital capacity[1] as well as pulmonary ventilation.

Table 24.—*Average lung ventilation per kilogram of body-weight with subject standing. (Values per minute.)*

Subject.	Body-weight without clothing.	Pulmonary ventilation (reduced).	Ventilation per kilogram of body-weight.
	kg.	*liters.*	*liter.*
A. J. O.	69.5	7.8	0.112
H. R. R.	70.0	7.0	.100
T. H. H.	54.5	6.5	.119
W. K.	49.2	6.5	.132
E. D. B.	57.0	9.1	.160
J. H. G.	68.0	10.6	.156
E. L. F.	70.4	10.6	.151
H. M. S.	60.4	10.0	.166

Pulse-Rate with Subject Standing.

The oscillograph for securing electro-cardiograms was not in a satisfactory working condition until the middle of March 1915, and the making of a few adjustments prevented further records for nearly a week. On this account, no pulse measurements were made for A. J. O. and the records are incomplete for T. H. H. and W. K. As explained in an earlier section (see p. 34), the difficulties experienced in the use of the oscillograph were so many that the string galvanometer was substituted in the early winter of 1915, and subsequently used for measuring the pulse-rates of E. D. B., E. L. F., J. H. G., and H. M. S. The data obtained are recorded and averaged in tables 3 to 7. (See pp. 43 to 55.)

---

[1] Dreyer, Lancet, 1919, **197**, p. 227; *ibid.*, 1920, **199**, p. 289. Dreyer and Hanson, The assessment of physical fitness by correlation of vital capacity and certain measurements of the body, London, 1920.

It is a recognized fact that the pulse-rate is liable to sudden and unexpected changes, even when the subject is at complete rest,[1] and that the rate may be stimulated by thought or anticipation.[2] It is, therefore, with considerable hesitation that the term "average standing pulse-rate" is used. It is necessary, however, to have some basis to work from and the term as here employed represents the general average of the records of each day for the individual subjects, regardless of whether they include one or more periods. For instance, with W. K. on March 16, the daily average of 81 is obtained from the record for the first period only[3] and on June 4 the rate of 74 is from the third period only, while that of 85 for June 1 is the average for four standing periods on that day. (See table 5, p. 44.) It may be justly said that the rates of 81 and 74 for March 16 and June 4 are given too much weight by this method of averaging, but it has not seemed necessary to undertake a more complicated method, as such a change would not affect materially the general picture of the variations in pulse-rate. This is especially true in view of the fact that on the days when both standing and walking experiments were made, the standing rate for the day, and not the average rate for all the standing experiments with that subject, has been used as the base-line in determining the change in the pulse-rate during the subsequent periods of walking on that particular day.

With these statements in mind, it is seen from table 4, page 44, that T. H. H. had an average pulse-rate on March 19 of 100, with variations on this date from 97 in the first period to 103 in the third. Three days later (March 22) the average rate was 91, with a range from 87 in the first period to 96 in the last period. The average for the two days was 96. On both days the pulse-rate increased during each succeeding period, indicating that the effort of continuous standing increased the work of the heart.

The first day on which H. R. R. was a regular subject (March 20), he had an average pulse-rate of 108. (See table 3.) While his pulse-rate was probably stimulated on this day, owing to the novelty of the experience, the average rates of 95 and 91 obtained on the other two days indicate that the subject had a normally high pulse-rate for the standing position. It was also noted that the pulse-rate of this subject while he was in the lying position was much higher than that of the other subjects. (See table 17, p. 91.) The average rate for three days of experimenting with him was 98. Excluding the high pulse-rate of the first day, it was 93. The change in the rate during the succeeding periods of the day is, on the whole, the reverse of that shown by T. H. H. and indicates that the psychical effect passed away more rapidly than the physical effort of standing increased the heart-rate, if, indeed, there were such an effect. This may be questioned in view of the decrease in the pulse-rate. H. R. R. was of a nervous type, while T. H. H. was phlegmatic.

---

[1] Benedict, Miles, Roth, and Smith, Carnegie Inst. Wash. Pub. No. 280, 1919, p. 389.

[2] Favill and White, Heart, 1917, **6**, p. 175; also, West and Savage, Arch. Intern. Med., 1918, **22**, p. 290.

[3] It should be emphasized that all counts were made photographically and several exposures were secured during each period. The average for each period thus represents almost invariably not less than three separate counts.

The first record with W. K. was made on March 11, 1915, when an average pulse-rate of 79 was obtained. This man had acted as subject for several days previous to this date. Consequently, if there had been any unusual stimulation on earlier days due to the novelty of the test, it had all disappeared when the first pulse-record was made, since the subsequent measurements with the subject standing, even to the close of experimenting with this subject in June, 1915, approximated this figure. This approximate uniformity may be seen by the detailed pulse-rate records given for W. K. in table 27, page 111. From table 5, we see that the highest period rate found during the standing experiments was 87 in the first period on March 17 and the fourth period of June 1; the lowest value was 73 in the second period on May 29. The daily average varied from 74 on May 29 and June 4 to 85 on June 1. There is no clear-cut evidence that the pulse-rate increased as the standing continued. On March 17 it tended to fall; on March 18 it had a tendency to increase; on the other days the changes were irregular and insignificant. The average standing pulse for this subject was 79 beats.

Owing to our difficulties with the oscillograph, records were not obtained with E. D. B. until November 29, 1915. At that time he had become fairly accustomed to the conditions, so that the novelty of the exercise played no rôle. The illustrative pulse-records in figure 8 (p. 34) are all for this man. Electro-cardiograms were obtained with E. D. B., standing, on 43 days. (See fig. 9, p. 98, and table 6, p. 46.) These records show pulse-rates ranging from 52 on February 19 to 96 in the first period on February 1. The low rate of February 19 is the average of three 1-minute records, taken four minutes apart, of 50, 52, and 53. It seems evident, therefore, that the value of 52 correctly represents the average standing pulse for this day and that the rate was lower on this date than on others. This is the lowest average pulse-rate of a man standing that we have observed, save in the case of a few subjects on prolonged low diet.[1] The high rate of 96 in the first period of February 1 is likewise the average of three counts of from 44 to 61 seconds, giving pulse-rates of 95, 93, and 99. These high figures and the high average for this day and for the day preceding may find some explanation in the fact that E. D. B. had not acted as subject for three weeks prior to January 31, owing to lameness (see p. 42). Accordingly an element of excitement may have been introduced by the fact that he was resuming the experiments. Furthermore, a note in the protocol for January 31 says "slight cold and hoarseness," and on February 1 the note is made that the "subject seemed to have a slight cold in the throat." It is possible, therefore, that the pulse-rate for these two days should not be included in the daily averages, although this has been done in computing the general average of 78 for this subject. If these are excluded, the average standing pulse-rate for E. D. B. is 77, a difference which is negligible.

---

[1] Benedict, Miles, Roth, and Smith, Carnegie Inst. Wash. Pub. No. 280, 1919, p. 413.

The few pulse-rates obtained with the laboratory assistants and recorded in table 7 (p. 55) give but little idea of the true pulse-rate during standing, as they are apparently influenced by other factors. The records for J. H. G. show a daily pulse-rate varying from 117 to 106. He found standing very irksome on January 18 and reported that his knees were "shaky" at the close of the standing experiment. He made no such comment on the other days. The pulse-rate of E. L. F. on January 21 showed a rapid increase during the first period as the experiment continued, rising from 87 after one minute of standing to 95 and 108 at intervals of 5 and 4 minutes, respectively. The other two standing periods on this date showed some increase, but not so large as this. On January 24 the statement is made in the protocols: "Subject all tired out at end of third period; complained of headache." He was apparently not in the best of physical condition on this day, but continued with the morning routine, three walking periods following the standing periods. H. M. S. on January 25 "found standing tiresome" and "was glad to start walking." The records for each period are unusually uniform. As evidence that the variations met with in the course of this study are due to the personal element and not to the technique, the records of H. M. S. are given in detail in table 25. It may be said that the age of this subject and his

TABLE 25.—*Detailed pulse-rate records for H. M. S., standing.*

Date and period.	First record.	Second record.	Third record.
1916.			
January 25:			
First............	96.7	97.7	....
Second..........	96.0	98.1	97.6
Third...........	95.4	100.9	....
January 26:			
First............	85.2	88.8	85.3
Second..........	86.1	....	88.8
Third...........	87.6	85.5	85.6

greater familiarity with the experimental technique resulted in a more nearly uniform pulse-rate, but evidently these factors did not prevent a stimulated pulse-rate on the first experimental day.

During the time of this study most of these men had also served as subjects in other respiration experiments in the Nutrition Laboratory. In these cases the men were lying quietly, and we thus have evidence as to the pulse-rates of the individual subjects under such conditions. The average results for four men with whom the pulse-rate was counted with a stethoscope have been averaged and are given in table 26, in which they are compared with the average pulse-rates obtained photographically for the same subjects in the standing position. The number of experimental periods in which records of the pulse-rate were obtained ranged for the lying position from 10 periods with E. D. B. to 128 periods with W. K., and for the standing position from 5 periods with T. H. H. to 105 periods with E. D. B.

Table 26.—*Comparison of the average pulse-rates of four subjects for the lying and standing positions. (Values per minute.)*

Subject.	No. of experimental periods.		Pulse-rate.			
	Lying position.	Standing position.	Lying position.	Standing position.	Increase for standing over lying.	Percentage increase.
H. R. R.	32	8	73	93	20	27
T. H. H.	64	5	59	96	37	63
W. K.	128	25	57	79	22	39
E. D. B.	10	105	58	78	20	34
Average	....	....	62	87	25	41
Squad A[1] (av. 11 men, reduced diet)	....	....	45	64	17	38
Squad B[1] (av. 11 men, normal diet.)	....	....	56	76	18	32

[1] Benedict, Miles, Roth, and Smith, Carnegie Inst. Wash. Pub. No. 280, 1919, table 93, p. 413.

The pulse-rate for the lying position is considerably higher for H. R. R. than for the others, confirming our impression of him as of a nervous temperament, and accounting in some degree for the high pulse-rate found for the standing position. With so high a pulse-rate for the basal value, the percentage increase for the standing position with H. R. R. is below the average, being 27 per cent. The reverse is true with T. H. H. In his case the influence of novelty in the standing experiment resulted in a pulse-rate of 96, which is probably abnormally high. This is the average of two days' records with five experimental periods, the pulse-rate on the first day averaging 100 and on the second day 91 beats per minute. With the other two subjects the data are sufficient to give a picture which is probably truer than that of T. H. H., these showing a percentage increase of 34 to 39 per cent for standing as compared with the rates found for the lying position.

In a publication recently issued from the Nutrition Laboratory,[1] some data were given on the change in the pulse-rate with two groups of 11 men each, one of these groups (Squad A) being on a reduced diet with a very much lowered basal metabolism, and the other (Squad B) on a normal diet. From the figures in table 26, it is seen that the pulse-rate of Squad A on a reduced diet increased 38 per cent for the standing position as compared with that found when the men were lying down. With the men in Squad B on normal diet, the pulse-rate for the standing position showed an increase of 32 per cent. These figures agree with those reported for the subjects of the present research. From the above comparison it may be said that the work of standing increases the pulse-rate approximately 35 per cent over that for the lying position.

TABLE 27.—*Detailed pulse records of W. K. during standing and walking experiments without food. (Values per minute.)*

Date.	Conditions.	Period.	Pulse-rate during period at approximately—			Average pulse-rate for period.
			2 min.	6 min.	10 min.	
1915 Mar. 11	Standing	Prelim.	81	....	[1]72	77
	Do	1	....	78	....	78
	Do	2	82	....	78	80
	Do	Interval	....	....	....	72
	Do	3	78	77	79	78
Mar. 16	Do	1	78	84	82	81
	Walking level	4	....	73	74	74
	Do	5	79	75	79	77
	Do	6	76	80	77	78
	Do	7	....	78	77	78
Mar. 17	Standing	Prelim.	83	....	78	81
	Do	1	83	87	90	87
	Do	2	81	83	82	82
	Do	3	75	77	78	77
	Walking level	4	73	75	77	75
	Do	5	73	....	....	73
	Do	6	....	....	77	77
	Standing	Final	84	....	....	84

[1] After 25 minutes of standing.

To note the changes in pulse-rate within the period, detailed data for the standing experiments of W. K. have been collected in table 27. The records were usually made at the second, sixth, and tenth minutes of the period. The pulse-rates obtained in the walking experiments on the same dates are also included. Table 27 likewise shows a few rates which were determined preliminary to the periods, in intervals between periods, and when the subject was standing after walking.

---

[1] Benedict, Miles, Roth, and Smith, Carnegie Inst. Wash. Pub. No. 280, 1919, p. 413, table 93.

TABLE 27.—*Detailed pulse records of W. K. during standing and walking experiments without food. (Values per minute.)*—Continued.

Date.	Conditions.	Period.	Pulse-rate during period at approximately—			Average pulse-rate for period.
			2 min.	6 min.	10 min.	
1915. May 18	Standing	Prelim.	[1]81	[2]74	....	78
	Do.	1	77	83	81	80
	Do.	2	79	81	83	81
	Do.	3	84	83	86	84
	Walking level	Prelim.	72	74	....	73
	Do.	4	76	79	77	77
	Do.	5	74	73	74	74
	Do.	6	76	77	....	77
	Do.	7	76	82	78	78
	Standing	Final	....	....	....	71
29	Do.	Prelim.	....	....	....	72
	Do.	1	71	75	78	75
	Do.	2	72	74	73	73
	Do.	3	71	74	77	74
	Walking grade, 15.3 p. ct.	4	133	136	137	135
	Do.	5	....	146	147	146
	Do.	6	147	150	151	149
	Standing	Final	124	109	106	113
June 1	Do.	1	82	88	88	86
	Do.	2	84	82	88	85
	Do.	3	79	82	84	81
	Do.	4	85	89	87	87
	Walking grade, 15.3 p. ct.	5	142	150	152	148
	Do.	6	155	156	....	155
	Do.	7	157	162	161	160
	Standing	Final	145	119	126	[3]126
2	Do.	Prelim.	....	....	....	76
	Do.	1	78	82	85	81
	Do.	2	74	77	83	78
	Do.	Interval	....	....	....	67
	Walking grade, 15.3 p. ct.	4	137	139	145	140
	Do.	5	143	149	149	147
	Do.	6	149	151	153	151
	Standing	Final	127	119	....	123
3	Do.	Prelim.	....	....	....	74
	Do.	1	76	79	83	79
	Do.	2	74	78	83	78
	Do.	3	79	77	80	79
	Marking time	4	....	73	75	74
	Do.	5	74	73	74	74
	Do.	6	73	77	77	76
	Do.	7	79	78	79	79
	Standing	Final	72	65	....	69
4	Do.	3	68	74	78	74
	Marking time	4	72	76	74	74
	Do.	5	72	74	75	74
	Do.	6	77	77	76	77
	Do.	7	73	75	76	75
	Standing	Final	67	68	....	67
14	Do.	Prelim.	....	....	....	83
	Do.	1	....	76	79	78
	Do.	3	74	72	76	74
	Walking grade, 20.0 p. ct.	4	155	158	161	158
	Do.	5	166	169	171	169
	Do.	6	....	173	174	174
	Standing	Final	157	137	....	147

[1] After 16 minutes of standing.

[2] After 12 minutes of standing.

[3] 15 minutes after end of period, pulse-rate 115.

An examination of the pulse-records for W. K. in the standing position show that, on the whole, the rate changed during the period toward a slightly higher level as the standing continued, this change being with few exceptions between 2 and 4 beats. The interval between periods was usually sufficient to bring the pulse-rate to the original daily level, as seen by a comparison of the first records obtained in each period. An exception is found to this on March 18. This increase in the pulse-rate during the standing period and the decrease during the interval between periods, notwithstanding the fact that the subject was standing in both cases, is probably due to the undoubted effort during the periods of measurement of standing motionless without any relaxation by change of position. Although the subject did not keep his muscles rigid during these periods, he neither moved his arms nor shifted his weight from one leg to the other. Furthermore, there was probably the added effect of consciousness of the progress of the experiment which tended to act as a psychical stimulus to the pulse-rate. It may likewise be noted from table 27, although the point will be referred to again (see p. 165), that the average pulse-rate of this subject in level walking was lower in several instances than the average of the preceding standing periods.

Rectal Body-Temperature with Subject Standing.

Relatively few observations were made of the body-temperature, and these were with but one subject (E. D. B.). Obviously, the principal interest of these observations is in indicating the influence of the work of walking. The averages of the records for the standing periods are given in table 6*a*, and are shown graphically in figure 9. In a few instances they represent but two readings taken at the beginning and end of the periods, respectively, but in the majority of cases the average is for some 5 to 7 readings, made at regular intervals during the period.

The daily average rectal temperature with this subject standing ranges from 36.36° C. on February 19 to 37.25° C. on February 1 and 23, and 37.33° C. on March 24, i. e., well within "normal" limits. The temperature of 36.36° C. on February 19 is for one period only, but is an average of 5 readings which show no greater deviation than on other days and the resistance thermometer had been worn by the subject 21 minutes before the first reading was taken; there seems to be no reason, therefore, for doubting the reliability of this value. In connection with the high value for February 23 (37.25° C.), the experimental sheet carries this notation: "Difficult to get good balance during the first period." "At end of third period, the galvanometer deflected with each step." "Thermometer check in afternoon found O. K." Apparently on this date there was some trouble with the insertion of the thermometer and the temperature as recorded is liable to contain some error. On February 1, when the body-temperature was also 37.25° C., the records state that the subject seemed to have a slight cold on this day, as well as on the day before. The temperature on January 31 was also high. The value for March 24 (37.33° C.) is the average for three periods, with all of the records relatively high, especially that for the first period. No comment appears on the experimental sheet for the day other than the statement twice made of "leads balanced." The general average rectal temperature with the subject standing shown for these 40 days, i. e., January 5 to April 15, 1916, is 36.89° C.

In subsequent sections, in comparing the changes in the body-temperature during walking, the general average temperature obtained with the subject standing has been used as a base-line for those days when no standing experiments were carried out. Though this method is not so exact as a comparison with a standing base-line obtained on the individual days, it is probably within the limits of error of any method employed for obtaining an accurate measure of the temperature of the body-mass. Benedict, Miles, and Johnson[1] have shown that there is a wide variation in the surface-temperature of the body and that proximity to large blood-vessels has a marked effect on body-temperature measurements. Records of the temperature in the rectum give the temperature of the body at that point only. It is easy to believe that a thermometer inserted into a large mass of fecal material on one day and into a practically empty rectum on another day would show considerable differences in temperature, particularly as the response to change in temperature would be slower when the mass of fecal matter was large. There is therefore a daily variation to be expected, no matter how carefully the thermometer is adjusted and the readings made.

In noting the temperature changes during this study, it appeared that even when the subject was standing quietly, with a preliminary interval long enough for the thermometer to become settled, there was a tendency for the temperature to increase during the period. To confirm this we have taken the first and last temperatures of all the periods and find that of the approximately 100 periods in which readings were obtained, 87 per cent show a higher temperature at the close of the standing period by an average of 0.07° C., and 9 per cent were lower at the close by an average of 0.04° C., while 4 per cent show no change. To determine whether or not this increase tended to accumulate during the interval between the periods, also whether the relaxation from motionless standing with removal of the mouthpiece and nose-clip was accompanied by a lowering of the temperature, a comparison was made of the temperatures recorded at the end of the standing periods with those noted during the intervals between the periods. In the majority of these cases there was no marked change, and such changes as were noted were almost wholly in the direction of a lowering of the temperature. That the temperature did not tend to rise,[1] as was the case during the periods when the subject was standing motionless, would indicate that the almost rigid position did tend to increase the body-temperature as recorded. This might be due to the increased effort made or to limitations in the radiation from the body resulting from the use of a blanket, or to an effort in breathing under the conditions of the period. The effort of motionless standing, therefore, seemed to cause a gradual rise in temperature, but this rise was not permanent and the average temperature of the succeeding periods remained very much like the average of the first period.

---

[1] Benedict, Miles, and Johnson, Proc. Nat. Acad. Sci., 1919, **5**, p. 218.

The curves of the body-temperature records for all of the standing periods have been plotted; lack of space prevents the printing of all of these, but a few typical curves have been reproduced in connection with subsequent walking experiments. (See fig. 14, p. 173, and figs. 33 to 37, pp. 269 to 275.) The observations within the periods proper are indicated by black points. The time when the subject began standing is marked by the figure 2. The beginning of walking is indicated by the figure 3 and of sitting by the figure 1. The temperatures, though showing some fluctuations, are fairly level for the standing portion as compared with the walking portions, while each standing period shows a tendency for the temperature to increase slightly, as previously stated.

Blood-Pressure with Subject Standing.

To secure data on the effect upon the blood-pressure of walking at various degrees of intensity, it was first necessary to obtain a base-line by noting the blood-pressure of the subject while he was standing. These data, which were found for E. D. B. only, are collected in table 6*a* for the period from March 20 to the close of the study. The method by which these measurements were made is described on page 37.

The blood-pressure during standing was determined on 20 days and in three periods on each day, except on April 10, when there were but two standing periods. The average blood-pressure for these 20 days was 117 mm., and varied from 109 mm. on March 29 to 125 mm. on April 8. The difference between the blood-pressures for consecutive periods varied from 0 to 5 mm., with an average variation of 3 mm. Of the 20 days, there were 13 on which the pressure in the last standing period was higher than the first by an average of 3.1 mm. and six days on which the value for the last period was lower than that for the first period by an average of 1.3 mm.; on one day there was no change. It would appear, therefore, that the effort of continued standing increased the blood-pressure slightly. For the wide range between the extremes of 109 for March 29 and 125 for April 8, no explanation can be found. The readings of the different determinations in each period on both dates are of the same character and it is believed that the blood-pressure on these days was approximately as here reported. In any event, all readings are within normal limits for a man of this age (23 years).

---

[1] It should be noted that the diurnal temperature variation curve is characterized by a tendency to rise rather than fall during the forenoon, i. e., during the hours these experiments were in progress.

EXPERIMENTS WITH HORIZONTAL WALKING.

Metabolism of Subjects While Walking on a Level.

After the extensive researches of Durig[1] and his co-workers and the report from this Laboratory on horizontal walking by Benedict and Murschhauser,[2] it would seem but little, if anything, could be added to this subject by multiplying the data. As a matter of fact, to study the influence of grade walking adequately, certain basic data for the individual subjects employed in grade-walking experiments, which pertain to their metabolism while they were walking on a level, are essential for the computation of the horizontal component in the analysis of the grade-walking experiments. Accordingly, horizontal-walking experiments were made with each of our subjects; in some instances the series extended over a considerable period of time.

Durig and his associates found that on the average the energy required with rates of walking below 80 meters per minute corresponded approximately to 0.55 gram-calorie for each horizontal kilogrammeter. Since there were rather considerable differences in the rates of walking in this present series of tests, the rate exceeding at times the normal average walking speed, it is obvious that grand averages would have little value for general comparison, and fundamental data for walking at the several speeds is essential for each series of grade-walking tests. Usually, however, the rates of walking ranged from 50 to 80 meters per minute, i. e., those normally used by an individual in "taking a walk," and a general picture of the results is thus worthy of short consideration; consequently, we shall first discuss the values without noting particularly the effect of change in the rate of walking.

Total Metabolism During Horizontal Walking.

The individual data for each subject are given in tables 8 to 12. The average results are also given for all the subjects in table 28, these being based primarily upon gross changes in the speed of walking, expressed in 5-meter intervals. The following notes and comments are to be looked upon primarily as supplementing the original data and in the nature of discussion of certain of the results. Stress is laid, however, only upon general figures, which take little, if any, account of differences in the rate of walking.

With H. R. R., six horizontal-walking experiments were made, with a total of 15 periods. (See table 8, p. 56.) The rate of walking varied from 59.9 to 67.7 meters per minute, with an average for the six days of 62.5 meters per minute. In the first experiment (March 20) there was an unusually high metabolism, the oxygen consumption being approximately 100 c. c. per minute more than on the next highest day, and the heat-production about 0.4 calorie higher. This difference is largely due to the results of the first period on this date, which possibly should have been rejected. The figures have, however, been allowed to stand and are used in calculating the average value. The total average oxygen consumption for H. R. R. was 867 c. c. per minute, with a heat-output of 4.17 calories per minute.

---

[1] Durig, Denkschr. d. math.-natur. Klasse d. kaiserl. Akad. d. Wissensch., 1909, **85**, p. 263.
[2] Benedict and Murschhauser, Carnegie Inst. Wash. Pub. No. 231, 1915.

With T. H. H. (table 9, p. 57) there were seven days on which experiments were made, with a total of 21 periods. The speed of walking ranged in the individual periods only from 62.4 to 68.2 meters per minute. February 25, the first day on which T. H. H. acted as subject, shows a much lower metabolism than that found on the other days, but the fact that in two of the periods there was a marked increase in the carbon-dioxide output with a simultaneous lowering of the oxygen consumption leads one to question the normality of the conditions on this day. In the experiments made from March 19 to April 5, there appears to have been no marked change in the metabolism. For the seven days on which horizontal-walking experiments were made with this subject, with a reasonably uniform daily speed, the average oxygen intake was 678 c. c. per minute and the average energy output 3.30 calories per minute.

The results for W. K. were obtained in 16 horizontal-walking experiments, with 52 experimental periods. (See table 10, p. 58.) The majority of the experiments were made within the month of March, so the picture is fairly continuous. The total heat-output had a tendency to decrease somewhat as time progressed, irrespective of the fact that the average speeds differed in those four weeks by a maximum of but 7 meters per minute from each other. The last horizontal-walking experiment was made in June, three months after most of the experiments were carried out. This day shows the lowest heat-output of any of the horizontal-walking experiments with W. K., but the speed at which the subject walked was also the lowest, namely, 57.1 meters per minute. With this man there was an apparent tendency for the oxygen consumption to be larger in the first periods of the day, with lower values each succeeding period. The average oxygen consumption was 563 c. c. per minute and the average heat-output 2.72 calories per minute.

The largest number of experiments with horizontal walking was made with E. D. B., these extending from October 9, 1915, to April 13, 1916. (See table 11, p. 60.) During this time measurements were made on 61 days, with 198 periods in all. The range in the daily average speed was very considerable, i. e., from 35.8 to 97.4 meters per minute. Since the extreme speeds at which E. D. B. walked were not natural, but forced, an average value has therefore but little significance. For comparison with the results obtained with other subjects, an average has been found for these days when the speed of walking fell within the ranges of 55 to 65 meters per minute. This shows a total average oxygen consumption per minute of 607 c. c. and a heat-output of 2.94 calories.

Considering the large number of determined respiratory quotients of E. D. B., it will be found that the quotient of the first period of the day is usually higher than that of subsequent periods and that the difference between the first and second periods is usually greater than that between the second and succeeding periods. This is apparently due to both the carbon dioxide and oxygen, for, in general, it may be noted that the elimination of the carbon dioxide decreased and the oxygen consumption increased in the second period. Since the periods were preceded by several minutes of preliminary walking, any tendency toward an unnatural ventilation of the lungs would probably have been eliminated before the period began. Furthermore, any change in volume of the ventilating system due to the warmth and moisture of the exhaled air would probably have been overcome by the time the final admission of oxygen was made. Such small increase as there was in the temperature of the soda-lime and sulphuric acid in the absorbers would therefore be practically alike in all periods and the effect would be to decrease the oxygen admitted to the system rather than to increase it. It would seem from a study of the respiratory quotient in this connection that there was a gradual change in the character of the material oxidized in the body. If this is not the case, and if the change in the oxygen consumption and respiratory quotient is in fact due to some fixed error in the technique, the heat-output as calculated for the first period is too high. Since the heat-output used, however, is ordinarily the average of from three to five periods, any error due to this cause has no significance in the general picture.

Of the three remaining subjects (see table 12, p. 68), the only special features to be noted in the results are that the heat-output for J. H. G. was the largest on his first day, also that his respiratory quotients are lower than those of the subjects previously discussed. The highest heat-output for E. L. F. was on his first day, although the rates of walking were fairly uniform for all three days. H. M. S. shows a low respiratory quotient, which is in keeping with the low respiratory quotients found in his standing experiments.

The average total metabolism for these men, walking at what may be called natural speeds, is shown in table 28. From this table it is seen that the heat-output per kilogram of body-weight per hour for the more natural speeds lying between 50 and 80 meters per minute ranged from 2.73 calories (E. D. B.) to 3.75 calories (H. R. R.). The gradual increase in the heat-output on the basis of body-weight is consistent throughout practically all the tests for all of the subjects. There is but one exception, i. e., with E. D. B. for 60 to 65 meters per minute, when the heat-output was higher than that with the succeeding speed of 65 to 70 meters per minute. It may be recalled that the series of experiments with a speed of 60 to 65 meters per minute was the first series with this subject.

Table 28.—*Average oxygen consumption and heat-output for subjects walking on a level at speeds between 35 and 100 meters per minute.*

Subject.	Speed.	Oxygen per minute.	Heat per minute.	Per kilogram of body-weight per hour.	
				Oxygen.	Heat.
	meters.	*c. c.*	*cals.*	*c. c.*	*cals.*
A. J. O.	60 to 65	712	3.46	617	2.99
H. R. R.	60 to 65	833	4.00	713	3.43
	65 to 70	902	4.37	775	3.75
T. H. H.	60 to 65	651	3.17	717	3.49
	65 to 70	692	3.36	763	3.70
W. K.	55 to 60	519	2.50	633	3.05
	60 to 65	558	2.68	679	3.27
	65 to 70	589	2.86	717	3.49
E. D. B.	35 to 40	467	2.26	492	2.38
	40 to 45	466	2.28	492	2.40
	45 to 50	467	2.29	492	2.41
	50 to 55	535	2.59	563	2.73
	55 to 60	563	2.73	592	2.88
	60 to 65	633	3.06	667	3.22
	65 to 70	586	2.87	617	3.02
	70 to 75	648	3.14	683	3.30
	75 to 80	678	3.31	713	3.48
	85 to 90	864	4.17	908	4.39
	90 to 100	901	4.40	950	4.63
J. H. G.	50 to 55	697	3.32	617	2.93
	55 to 60	710	3.40	625	3.00
E. L. F.	45 to 50	674	3.24	575	2.76
	50 to 55	717	3.46	604	2.95
H. M. S.	45 to 50	601	2.85	596	2.83
	50 to 55	652	3.11	646	3.09

The increase for the heat per kilogram of body-weight for each increase of 5 meters in speed is not uniform, either for the different subjects or for the different speeds. Such changes as 2 per cent for J. H. G. in passing from a speed of 50 to 55 meters per minute to 55 to 60 meters per minute, and 9 per cent for H. R. R. in passing from a speed of 60 to 65 meters to 65 to 70 meters per minute, are noted. In the majority of cases the variation ranges from 5 to 10 per cent for each increase of 5 meters in speed. It may be stated from the data available in the table that the heat-output per kilogram of body-weight for all ordinary speeds of walking, such as might be taken as a "constitutional" by a person of moderate activity, would be 3.35 calories per hour per kilogram of body-weight.

Increment in Metabolism due to Horizontal Walking.

As has been made evident, the values in tables 8 to 12 take no account of the basal standing requirements and only incidentally of the speeds. This has been done in tables 29 to 33, in which are shown the body-weight of the subject with clothing, the distance walked per minute, the horizontal kilogrammeters, i. e., the distance multiplied by the body-weight, the number of steps taken per minute, the elevation of the body in walking (step-lift), the work done due to such elevation, and both the total heat-output and, of main importance here, the increments in the heat-output over the standing requirements.

Table 29.—*Increase in heat-output of A. J. O. and H. R. R. during horizontal walking in experiments without food. (Values per minute.)*

Date and condition.	(*a*) Body-weight with clothing.	(*b*) Distance.	(*c*) Horizontal kilogrammeters. $a \times b$	(*d*) No. of steps.	(*e*) Raising of body (step-lift).	(*f*) Work due to step-lift. $a \times e$	(*g*) Total heat.	Increment in heat above standing-value.			
								(*h*) Total increase.	(*i*) Per horizontal kilogrammeter. $\frac{h \times 1{,}000}{c}$	(*j*) Per kilogrammeter of step-lift. $\frac{h \times 1{,}000}{f}$	(*k*) Proportion of increase due to step-lift. $\frac{2.34 \times 100}{j}$
A. J. O. 1915. Feb. 15:	*kg.*	*meters.*			*meters.*	*kg. m.*	*cals.*	*cals.*	*gm.-cal.*	*gm.-cals.*	*p. ct.*
Standing...	......	......	....	....	......	....	1.32	.....	....	....	....
Walking...	74.5	[1]63.1	4,701	....	......	....	3.28	1.96	0.417	....	....
Feb. 24:											
Standing...	......	......	....	....	......	....	1.30	.....	....	....	....
Walking...	......	63.1	4,733	96.9	1.72	129.0	3.67	2.37	.501	18.4	13
	......	63.8	4,785	96.8	2.01	151.0	3.63	2.33	.487	15.4	15
Average .	75.0	63.5	....	96.9	1.87	....	......	2.35	.494	16.9	14
Mar. 2:											
Standing...	......	......	....	....	......	....	[2]1.31	.....	....	....	....
Walking...	......	63.8	4,721	98.7	2.41	178.0	3.58	2.27	.481	12.8	18
	......	60.7	4,492	93.8	2.01	149.0	3.37	2.06	.459	13.8	17
	......	63.6	4,706	97.9	1.85	137.0	3.27	1.96	.416	14.3	16
Average .	74.0	62.7	....	96.8	2.09	....	......	2.10	.452	13.6	17
H. R. R. 1915. Mar. 20:											
Standing...	......	......	....	....	......	....	1.52	.....	....	....	....
Walking...	......	67.7	5,030	105.4	.85	63.2	4.88	3.36	.668	53.2	4
	......	64.5	4,792	102.2	.99	73.6	4.48	2.96	.618	40.2	6
Average .	74.3	66.1	....	103.8	.92	....	......	3.16	.643	46.7	5

[1] Average of values for Feb. 24 and March 2. See table 8, p. 56.

[2] Average of values for Feb. 15, 24, and 27. See table 3, p. 43.

TABLE 29.—*Increase in heat-output of A. J. O. and H. R. R. during horizontal walking in experiments without food. (Values per minute.)*—Continued.

Date and condition.	(a) Body-weight with clothing.	(b) Distance.	(c) Horizontal kilogrammeters. a × b	(d) No. of steps.	(e) Raising of body (step-lift).	(f) Work due to step-lift. a × e	(g) Total heat.	Increment in heat above standing-value.			
								(h) Total increase.	(i) Per horizontal kilogrammeter. h × 1,000 / c	(j) Per kilogrammeter of step-lift. h × 1,000 / f	(k) Proportion of increase due to step-lift. 2.34 × 100 / j
H. R. R. (Cont.) 1915											
Mar. 27:	*kg.*	*meters.*			*meters.*	*kg. m.*	*cals.*	*cals.*	*gm.-cal.*	*gm.-cals.*	*p. ct.*
Standing...							[1]1.34				
Walking...		65.8	4,823	102.8	1.24	90.9	4.32	2.98	0.618	32.8	7
		67.2	4,926	102.6	1.47	107.8	4.31	2.97	.603	27.6	9
		67.5	4,948	102.4	1.34	98.2	4.36	3.02	.610	30.8	8
Average..	73.3	66.8		102.6	1.35			2.99	.610	30.4	8
Apr. 3:											
Standing...							[1]1.34				
Walking...		60.9	4,367	95.2	1.10	78.9	4.05	2.71	.621	34.3	7
		60.5	4,338	95.0	1.11	79.6	4.10	2.76	.636	34.7	7
		60.0	4,302	95.6	1.12	80.3	4.12	2.78	.646	34.6	7
Average..	71.7	60.5		95.3	1.11			2.75	.634	34.5	7
Apr. 10:											
Standing...							1.37				
Walking...	72.2	61.1	4,411	99.0	1.02	73.6	4.27	2.90	.657	39.4	6
Apr. 17:											
Standing...							1.31				
Walking...		60.0	4,332	98.4	1.00	72.2	3.87	2.56	.591	35.5	7
		59.9	4,325	97.8	1.10	79.4	3.87	2.56	.592	32.2	7
Average..	72.2	60.0		98.1	1.05			2.56	.592	33.9	7
Apr. 24:											
Standing...							[1]1.34				
Walking...		61.8	4,363	99.2	1.19	84.0	3.87	2.53	.580	30.1	8
		60.2	4,250	95.0	1.15	81.2	3.76	2.42	.569	29.8	8
		60.6	4,278	94.8	1.25	88.3	3.76	2.41	.563	27.3	9
		60.1	4,243	96.0	1.20	84.7	3.82	2.48	.584	29.3	8
Average..	70.6	60.7		98.3	1.20			2.46	.574	29.1	8

[1] Average of values for April 10 and 17. See table 3, p. 43.

TABLE 30.—*Increase in heat-output of T. H. H. during horizontal walking in experiments without food. (Values per minute.)*

Date and condition.	(a) Body-weight with clothing.	(b) Distance.	(c) Horizontal kilogram-meters. $a \times b$	(d) No. of steps.	(e) Raising of body (step-lift).	(f) Work due to step-lift. $a \times e$	(g) Total heat.	Increment in heat above standing-value.			
								(h) Total increase.	(i) Per horizontal kilogrammeter. $\frac{h \times 1{,}000}{c}$	(j) Per kilogrammeter of step-lift. $\frac{h \times 1{,}000}{f}$	(k) Proportion of increase due to step-lift. $\frac{2.34 \times 100}{j}$
1915. Feb. 25:	*kg.*	*meters.*			*meters.*	*kg. m.*	*cals.*	*cals.*	*gm.-cal.*	*gm.-cals.*	*p. ct.*
Standing							1.10				
Walking		63.4	3,690	100.7	1.60	93.1	3.02	1.92	0.520	20.6	11
		63.7	3,707	98.3	1.18	68.7	2.98	1.88	.507	27.4	9
		63.7	3,707	97.9	2.04	118.7	2.99	1.89	.510	15.9	15
Average	58.2	63.6		99.0	1.61			1.90	.512	21.3	12
Mar. 19:											
Standing							1.14				
Walking		65.7	3,824	107.0	1.58	92.0	3.44	2.30	.601	25.0	9
		66.7	3,882	106.4	1.74	101.3	3.43	2.29	.590	22.6	10
		67.1	3,905	106.2	1.85	107.7	3.49	2.35	.602	21.8	11
		67.8	3,946	106.0	1.73	100.7	3.41	2.27	.575	22.5	10
Average	58.2	66.8		106.4	1.73			2.30	.592	23.0	10
Mar. 22:											
Standing							1.08				
Walking		67.5	3,922	106.6	1.27	73.8	3.47	2.39	.609	32.4	7
		67.5	3,922	105.0	1.30	75.5	3.30	2.22	.566	29.4	8
Average	58.1	67.5		105.8	1.29			2.31	.588	30.9	8
Mar. 24:											
Standing							[1]1.11				
Walking		67.4	3,788	104.8	1.86	104.5	3.34	2.23	.589	21.3	11
		68.1	3,827	104.2	1.82	102.3	3.22	2.11	.551	20.6	11
		67.8	3,810	103.6	1.80	101.2	3.19	2.08	.546	20.6	11
Average	56.2	67.8		104.2	1.83			2.13	.562	20.8	11
Mar. 26:											
Standing							[1]1.11				
Walking		65.9	3,697	100.8	2.08	116.7	3.32	2.21	.598	18.9	12
		67.6	3,792	101.2	2.16	121.2	3.18	2.07	.546	16.1	15
		68.2	3,826	102.0	2.16	121.2	3.15	2.04	.533	16.1	15
Average	56.1	67.2		101.3	2.13			2.11	.559	17.0	14
Mar. 30:											
Standing							[1]1.11				
Walking		65.9	3,704	102.0	2.12	119.1	3.35	2.24	.605	18.8	12
		66.8	3,754	102.2	2.10	118.0	3.39	2.28	.607	19.3	12
		63.5	3,569	99.8	1.87	105.1	3.27	2.16	.605	20.6	11
Average	56.2	65.4		101.3	2.03			2.23	.606	19.6	12

[1] Average of values for Feb. 25, March 19 and 22. See table 4, p. 44.

Table 30.—*Increase in heat-output of T. H. H. during horizontal walking in experiments without food. (Values per minute.)*—Continued.

Date and condition.	(*a*) Body-weight with clothing.	(*b*) Distance.	(*c*) Horizontal kilogrammeters. $a \times b$	(*d*) No. of steps.	(*e*) Raising of body (step-lift).	(*f*) Work due to step-lift. $a \times e$	(*g*) Total heat.	Increment in heat above standing-value. (*h*) Total increase.	(*i*) Per horizontal kilogrammeter. $\frac{h \times 1{,}000}{c}$	(*j*) Per kilogrammeter of step-lift. $\frac{h \times 1{,}000}{f}$	(*k*) Proportion of increase due to step-lift. $\frac{2.34 \times 100}{j}$
1915. Apr. 5:	*kg.*	*meters.*			*meters.*	*kg. m.*	*cals.*	*cals.*	*gm.-cal.*	*gm.-cals.*	*p. ct.*
Standing...	......	......	....	....	......	....	[1]1.11	......	....	....	....
Walking...	......	62.4	3,538	99.4	1.69	95.8	3.36	2.25	0.636	23.5	10
	......	62.7	3,555	100.4	1.80	102.1	3.35	2.24	.630	21.9	11
	......	63.2	3,583	100.8	1.87	106.0	3.42	2.31	.645	21.8	11
Average .	56.7	62.8	....	100.2	1.79	....	......	2.27	.637	22.4	11

[1] Average of values for Feb. 25, March 19, and 22. See table 4, p. 44.

Table 31.—*Increase in heat-output of W. K. during horizontal walking in experiments without food. (Values per minute.)*

Date and condition.	(*a*) Body-weight with clothing.	(*b*) Distance.	(*c*) Horizontal kilogrammeters. $a \times b$	(*d*) No. of steps.	(*e*) Raising of body (step-lift).	(*f*) Work due to step-lift. $a \times e$	(*g*) Total heat.	Increment in heat above standing-value. (*h*) Total increase.	(*i*) Per horizontal kilogrammeter. $\frac{h \times 1{,}000}{c}$	(*j*) Per kilogrammeter of step-lift. $\frac{h \times 1{,}000}{f}$	(*k*) Proportion of increase due to step-lift. $\frac{2.34 \times 100}{j}$
1915. Feb. 26:	*kg.*	*meters.*			*meters.*	*kg. m.*	*cals.*	*cals.*	*gm.-cal.*	*gm.-cals.*	*p. ct.*
Standing...	......	......	....	....	......	....	1.03	......	....	....	....
Walking...	52.1	64.4	3,355	114.7	1.40	72.9	2.55	1.52	0.453	20.9	11
Mar. 4:											
Standing...	......	......	....	....	......	....	[1]1.10	......	....	....	....
Walking...	......	64.0	3,360	115.4	1.39	73.0	3.06	1.96	.583	26.9	9
	......	62.9	3,302	113.0	1.22	64.1	2.98	1.88	.569	29.3	8
	......	66.0	3,465	115.2	1.21	63.5	3.08	1.98	.571	31.2	8
Average .	52.5	64.3	....	114.5	1.27	....	......	1.94	.574	29.1	8
Mar. 5:											
Standing...	......	......	....	....	......	....	[1]1.10	......	....	....	....
Walking...	......	65.3	3,435	115.3	1.56	82.0	2.93	1.83	.533	22.3	11
	......	65.9	3,466	114.4	1.60	84.2	2.84	1.74	.502	20.7	11
	......	66.2	3,482	115.2	1.49	78.4	2.88	1.78	.511	22.7	10
Average .	52.6	65.8	....	115.0	1.55	....	......	1.78	.515	21.9	11

[1] Average of values obtained in experiments without food with subject standing, February 26 to June 14, 1915, nclusive. (See table 5, page 44.)

TABLE 31.—*Increase in heat-output of W. K. during horizontal walking in experiments without food. (Values per minute.)*—Continued.

Date and condition.	(*a*) Body-weight with clothing.	(*b*) Distance.	(*c*) Horizontal kilogrammeters. *a* × *b*	(*d*) No. of steps.	(*e*) Raising of body (step-lift).	(*f*) Work due to step-lift. *a* × *e*	(*g*) Total heat.	Increment in heat above standing-value. (*h*) Total increase.	(*i*) Per horizontal kilogrammeter. *h* ×1,000 / *c*	(*j*) Per kilogrammeter of step-lift. *h* ×1,000 / *f*	(*k*) Proportion of increase due to step-lift. 2.34 ×100 / *j*
1915. Mar. 8:	*kg.*	*meters.*			*meters.*	*kg. m.*	*cals.*	*cals.*	*gm.-cal.*	*gm.-cals.*	*p. ct.*
Standing...	......	......	....	....	......	....	[1]1.10	......	....	....	....
Walking...	......	66.4	3,486	116.6	1.48	77.7	2.99	1.89	0.542	24.3	10
	......	66.6	3,497	116.0	1.52	79.8	2.87	1.77	.506	22.2	11
	......	66.6	3,497	115.6	1.46	76.7	2.83	1.73	.495	22.6	10
Average .	52.5	66.5	....	116.1	1.49	....	......	1.80	.514	23.0	10
Mar. 9:											
Standing...	......	......	....	....	......	....	[1]1.10	......	....	....	....
Walking...	......	66.0	3,439	115.6	1.13	58.9	3.01	1.91	.555	32.4	7
	......	62.5	3,256	108.6	.91	47.4	2.65	1.55	.476	32.7	7
	......	62.2	3,241	109.0	1.00	52.1	2.57	1.47	.454	27.3	9
	......	58.6	3,053	107.6	.83	43.2	2.47	1.37	.449	31.7	7
Average .	52.1	62.3	....	110.2	.97	....	......	1.58	.484	31.0	8
Mar. 12:											
Standing...	......	......	....	....	......	....	1.05	......	....	....	....
Walking...	......	60.9	3,179	111.2	1.17	61.1	2.82	1.77	.557	29.0	8
	......	58.5	3,054	109.8	1.13	59.0	2.48	1.43	.468	24.2	10
	......	68.2	3,560	117.6	1.33	69.4	2.76	1.71	.480	24.6	9
Average .	52.2	62.5	....	112.9	1.21	....	......	1.64	.502	25.9	9
Mar. 13:											
Standing...	......	......	....	....	......	....	1.21	......	....	....	....
Walking...	......	65.1	3,333	114.0	1.01	51.7	2.87	1.66	.498	32.1	8
	......	64.7	3,313	113.0	1.04	53.2	2.78	1.57	.474	29.5	8
	......	59.4	3,041	108.0	.95	48.6	2.85	1.64	.539	33.7	7
	......	59.1	3,026	107.4	1.26	64.5	2.63	1.42	.469	22.0	11
Average .	51.2	62.1	....	110.6	1.07	....	......	1.57	.495	29.3	8
Mar. 16:											
Standing...	......	......	....	....	......	....	1.03	......	....	....	....
Walking...	......	59.2	3,108	109.8	.70	36.8	2.70	1.67	.537	45.4	5
	......	62.3	3,271	112.4	.87	45.7	2.64	1.61	.492	35.2	7
	......	60.9	3,197	107.2	.85	44.6	2.86	1.83	.572	41.0	6
	......	60.6	3,182	103.6	.81	42.5	2.69	1.66	.522	39.1	6
Average .	52.5	60.8	....	108.3	.81	....	......	1.69	.531	40.2	6

[1] Average of values obtained in experiments without food with subject standing, February 26 to June 14, 1915, inclusive. (See table 5, page 44.)

TABLE 31.—*Increase in heat-output of W. K. during horizontal walking in experiments without food. (Values per minute.)*—Continued.

Date and condition.	(a) Body-weight with clothing.	(b) Distance.	(c) Horizontal kilogram-meters. a × b	(d) No. of steps.	(e) Raising of body (step-lift).	(f) Work due to step-lift. a × e	(g) Total heat.	Increment in heat above standing-value.			
								(h) Total increase.	(i) Per horizontal kilogrammeter. h ×1,000 / c	(j) Per kilogrammeter of step-lift. h ×1,000 / f	(k) Proportion of increase due to step-lift. 2.34 ×100 / j
1915. Mar. 17:	*kg.*	*meters.*			*meters.*	*kg. m.*	*cals.*	*cals.*	*gm.-cal.*	*gm.-cals.*	*p. ct.*
Standing...	......	......	......	......	......	......	1.21	......	......	......	......
Walking...	......	67.3	3,520	117.2	1.41	73.7	2.99	1.78	0.506	24.2	10
	......	67.4	3,525	116.8	1.48	77.4	2.77	1.56	.443	20.2	12
	......	67.8	3,546	116.2	1.42	74.3	2.78	1.57	.443	21.1	11
	......	67.5	3,530	114.6	1.51	79.0	2.76	1.55	.439	19.6	12
Average .	52.3	67.5	......	116.2	1.46	......	......	1.62	.458	21.3	11
Mar. 18:											
Standing...	......	......	......	......	......	......	1.03	......	......	......	......
Walking...	......	62.5	3,288	108.0	1.05	55.2	2.78	1.75	.532	31.7	7
	......	58.4	3,072	100.0	.84	44.2	2.60	1.57	.511	35.5	7
	......	60.8	3,198	106.2	1.12	58.9	2.58	1.55	.485	26.3	9
	......	58.8	3,093	104.2	1.01	53.1	2.54	1.51	.488	28.4	8
Average .	52.6	60.1	......	104.6	1.01	......	......	1.60	.504	30.5	8
Mar. 23:											
Standing...	......	......	......	......	......	......	[1]1.10	......	......	......	......
Walking...	......	64.3	3,247	111.6	1.12	56.6	2.82	1.72	.530	30.4	8
	......	66.4	3,353	113.4	1.34	67.7	2.77	1.67	.498	24.7	10
	......	66.5	3,358	111.4	1.39	70.2	2.70	1.60	.476	22.8	10
Average .	50.5	65.7	......	112.1	1.28	......	......	1.66	.501	26.0	9
Mar. 25:											
Standing...	......	......	......	......	......	......	[1]1.10	......	......	......	......
Walking...	......	67.3	3,399	114.6	2.02	102.0	3.00	1.90	.559	18.6	13
	......	67.5	3,409	113.4	2.07	104.5	2.99	1.69	.496	16.2	14
	......	67.0	3,384	110.2	1.99	100.5	2.72	1.62	.479	16.1	15
Average .	50.5	67.3	......	112.7	2.03	......	......	1.74	.511	17.0	14
Mar. 29:											
Standing...	......	......	......	......	......	......	[1]1.10	......	......	......	......
Walking...	......	63.3	3,178	109.0	1.31	65.8	2.58	1.48	.466	22.5	10
	......	60.8	3,052	108.2	1.06	53.2	2.55	1.45	.475	27.3	9
	......	62.8	3,153	110.6	1.15	57.7	2.54	1.44	.457	25.0	9
Average .	50.2	62.3	......	109.3	1.17	......	......	1.46	.466	24.9	10

[1] Average of values obtained in experiments without food with subject standing, February 26 to June 14, 1915, inclusive. (See table 5, page 44.)

TABLE 31.—*Increase in heat-output of W. K. during horizontal walking in experiments without food. (Values per minute.)*—Continued.

Date and condition.	(*a*)	(*b*)	(*c*)	(*d*)	(*e*)	(*f*)	(*g*)	Increment in heat above standing-value.			
	Body-weight with clothing.	Distance.	Horizontal kilogram-meters. $a \times b$	No. of steps.	Raising of body (step-lift).	Work due to step-lift. $a \times e$	Total heat.	(*h*) Total increase.	(*i*) Per horizontal kilogram-meter. $\frac{h \times 1{,}000}{c}$	(*j*) Per kilogram-meter of step-lift. $\frac{h \times 1{,}000}{f}$	(*k*) Proportion of increase due to step-lift. $\frac{2.34 \times 100}{j}$
1915											
Mar. 31:	*kg.*	*meters.*			*meters.*	*kg. m.*	*cals.*	*cals.*	*gm.-cal.*	*gm.-cals.*	*p. ct.*
Standing...	......	......	......	......	......	......	[1]1.10	......	......	......	......
Walking...	......	64.8	3,305	108.2	1.17	59.7	2.58	1.48	0.448	24.8	9
	......	65.8	3,356	109.8	1.20	61.2	2.61	1.51	.450	24.7	10
	......	64.8	3,305	109.6	1.18	60.2	2.55	1.45	.439	24.1	10
	......	64.9	3,310	107.6	1.17	59.7	2.50	1.40	.423	23.5	10
Average .	51.0	65.1	......	108.8	1.18	......	......	1.46	.440	24.3	10
June 23:											
Standing...	......	......	......	......	......	......	[1]1.10	......	......	......	......
Walking...	......	58.2	2,904	108.0	1.30	64.9	2.31	1.21	.417	18.6	13
	......	57.1	2,849	106.0	1.36	67.9	2.28	1.18	.414	17.4	13
	......	56.0	2,794	105.4	1.19	59.4	2.21	1.11	.397	18.7	13
Average .	49.9	57.1	......	106.5	1.28	......	......	1.17	.409	18.2	13

[1] Average of values obtained in experiments without food with subject standing, February 26 to June 14, 1915, inclusive. (See table 5, page 44.)

TABLE 32.—*Increase in heat-output of E. D. B. during horizontal walking in experiments without food. (Values per minute.)*

Date and condition.	(*a*)	(*b*)	(*c*)	(*d*)	(*e*)	(*f*)	(*g*)	Increment in heat above standing-value.			
	Body-weight with clothing.	Distance.	Horizontal kilogram-meters. $a \times b$	No. of steps.	Raising of body (step-lift).	Work due to step-lift. $a \times e$	Total heat.	(*h*) Total increase.	(*i*) Per horizontal kilogram-meter. $\frac{h \times 1{,}000}{c}$	(*j*) Per kilogram-meter of step-lift. $\frac{h \times 1{,}000}{f}$	(*k*) Proportion of increase due to step-lift. $\frac{2.34 \times 100}{j}$
1915.											
Oct. 9:	*kg.*	*meters.*			*meters.*	*kg. m.*	*cals.*	*cals.*	*gm.-cal.*	*gm.-cals.*	*p. ct.*
Standing...	......	......	......	......	......	......	1.19	......	......	......	......
Walking...	......	57.8	3,468	94.2	......	......	3.36	2.17	0.626	......	......
	......	56.4	3,384	91.8	1.30	78.00	3.15	1.96	.579	25.1	9
Average .	60.0	57.1	......	93.0	1.30	......	......	2.07	.603	25.1	9

TABLE 32.—*Increase in heat-output of E. D. B. during horizontal walking in experiments without food. (Values per minute.)*—Continued.

Date and condition.	(*a*) Body-weight with clothing.	(*b*) Distance.	(*c*) Horizontal kilogrammeters. *a* × *b*	(*d*) No. of steps.	(*e*) Raising of body (step-lift).	(*f*) Work due to step-lift. *a* × *e*	(*g*) Total heat.	Increment in heat above standing-value. (*h*) Total increase.	(*i*) Per horizontal kilogrammeter. *h* ×1,000 / *c*	(*j*) Per kilogrammeter of step-lift. *h* ×1,000 / *f*	(*k*) Proportion of increase due to step-lift. 2.34 ×100 / *j*
1915. Oct. 11:	*kg.*	*meters.*			*meters.*	*kg. m.*	*cals.*	*cals.*	*gm.-cal.*	*gm.-cals.*	*p. ct.*
Standing...	......	......	......	......	......	....	1.13	......	....	....	....
Walking...	......	56.3	3,401	89.0	1.45	87.58	2.99	1.86	0.547	21.2	11
	......	53.7	3,243	96.8	1.34	80.94	2.98	1.85	.570	22.9	10
Average .	60.4	55.0	....	92.9	1.40	....	......	1.86	.559	22.1	11
Oct. 13:											
Standing...	......	......	......	......	......	....	1.12	......	....	....	....
Walking...	60.2	55.8	3,359	87.0	1.34	80.67	2.93	1.81	.539	22.4	10
Oct. 14:											
Standing...	......	......	......	......	......	....	1.13	......	....	....	....
Walking...	......	55.3	3,318	88.4	1.34	80.40	2.80	1.67	.503	20.8	11
	......	54.2	3,252	88.2	1.34	80.40	2.85	1.72	.529	21.4	11
	......	54.1	3,246	87.8	1.34	80.40	2.91	1.78	.548	22.1	11
Average .	60.0	54.5	....	88.1	1.34	....	......	1.72	.527	21.4	11
Oct. 15:											
Standing...	......	......	......	......	......	....	1.10	......	....	....	....
Walking...	......	55.4	3,252	88.9	1.24	72.79	2.77	1.67	.514	22.9	10
	......	54.3	3,187	88.1	......	....	2.83	1.73	.543	....	....
	......	53.6	3,146	89.4	1.06	62.22	2.90	1.80	.572	28.9	8
Average .	58.7	54.4	....	88.8	1.15	....	......	1.73	.543	25.9	9
Oct. 16:											
Standing...	......	......	......	......	......	....	1.06	......	....	....	....
Walking...	......	65.2	3,834	98.0	1.65	97.02	2.95	1.89	.493	19.5	13
	......	64.9	3,816	97.4	1.74	102.31	3.01	1.95	.511	19.1	12
	......	65.0	3,822	97.6	1.69	99.37	3.05	1.99	.521	20.0	12
	......	64.9	3,816	97.4	1.85	108.78	3.02	1.96	.514	18.0	13
Average .	58.8	65.0	....	97.6	1.73	....	......	1.95	.510	19.2	12
Oct. 18:											
Standing...	......	......	......	......	......	....	1.12	......	....	....	....
Walking...	......	63.4	3,760	96.6	1.49	88.36	2.87	1.75	.465	19.8	12
	......	64.5	3,825	97.2	1.85	109.71	3.01	1.89	.494	17.2	14
	......	64.4	3,819	94.4	1.83	108.52	2.95	1.83	.479	16.9	14
	......	64.8	3,843	97.4	1.93	114.45	3.01	1.89	.492	16.5	14
Average .	59.3	64.3	....	96.4	1.78	....	......	1.84	.483	17.6	14

TABLE 32.—*Increase in heat-output of E. D. B. during horizontal walking in experiments without food. (Values per minute.)*—Continued.

Date and condition.	(*a*) Body-weight with clothing.	(*b*) Distance.	(*c*) Horizontal kilogrammeters. *a* × *b*	(*d*) No. of steps.	(*e*) Raising of body (step-lift).	(*f*) Work due to step-lift. *a* × *e*	(*g*) Total heat.	Increment in heat above standing-value.			
								(*h*) Total increase.	(*i*) Per horizontal kilogrammeter. $\frac{h \times 1{,}000}{c}$	(*j*) Per kilogrammeter of step-lift. $\frac{h \times 1{,}000}{f}$	(*k*) Proportion of increase due to step-lift. $\frac{2.34 \times 100}{j}$
1915. Oct. 19:	*kg.*	*meters.*			*meters.*	*kg. m.*	*cals.*	*cals.*	*gm.-cal.*	*gm.-cals.*	*p. ct.*
Standing...	......	......		......	......	....	1.14	......	....	....	....
Walking...	......	64.6	3,818	97.0	1.69	99.88	2.90	1.76	0.461	17.6	13
	......	64.1	3,788	96.4	1.89	111.70	3.14	2.00	.528	17.9	13
	......	63.9	3,776	96.4	1.89	111.70	2.97	1.83	.485	16.4	14
	......	64.5	3,812	96.2	1.85	109.34	3.19	2.05	.538	18.8	12
Average .	59.1	64.3	....	96.5	1.83	....	......	1.91	.503	17.7	13
Oct. 20:											
Standing...	......	......	......	......	......	....	1.13	......	....	....	....
Walking...	......	64.6	3,798	97.4	1.85	108.78	3.00	1.87	.492	17.2	14
	......	64.4	3,787	97.0	1.89	111.13	3.13	2.00	.528	18.0	13
	......	64.7	3,804	97.8	1.85	108.78	3.12	1.99	.523	18.3	13
	......	64.5	3,793	97.8	1.85	108.78	3.10	1.97	.519	18.2	13
	......	64.7	3,804	98.2	1.93	113.48	3.11	1.98	.521	17.5	13
Average .	58.8	64.6	....	97.6	1.87	....	......	1.96	.517	17.8	13
Oct. 21:											
Standing...	......	......	......	......	......	....	1.08	......	....	....	....
Walking...	......	63.8	3,828	98.4	......	....	2.97	1.89	.494	....	....
	......	63.6	3,816	97.6	1.85	111.00	3.07	1.99	.521	17.9	13
	......	63.7	3,822	97.0	1.89	113.40	3.08	2.00	.523	17.5	13
	......	63.8	3,828	96.8	1.89	113.40	3.11	2.03	.530	17.9	13
	......	64.3	3,858	96.7	1.86	111.60	3.07	1.99	.516	17.8	13
Average .	60.0	63.8	....	97.3	1.87	....	......	1.98	.517	17.8	13
Oct 22:											
Standing...	......	......	......	......	......	....	1.06	......	....	....	....
Walking...	......	71.6	4,246	101.0	2.20	130.46	3.12	2.06	.485	15.8	15
	......	72.6	4,305	100.6	1.97	116.82	3.17	2.11	.490	18.1	13
	......	72.6	4,305	99.6	2.01	119.19	3.20	2.14	.497	18.0	13
	......	72.4	4,293	100.7	......	....	3.22	2.16	.503	....	....
Average .	59.3	72.3	....	100.5	2.06	....	......	2.12	.494	17.3	14
Oct. 23:											
Standing...	......	......	......	......	......	....	1.07	......	....	....	....
Walking...	......	71.6	4,260	101.8	1.99	118.41	3.23	2.16	.507	18.3	13
	......	72.4	4,308	101.0	2.01	119.60	3.25	2.18	.506	18.1	13
	......	72.2	4,296	100.6	2.20	130.90	3.19	2.12	.493	16.2	14
	......	72.6	4,320	100.8	2.30	136.85	3.25	2.18	.505	15.9	15
Average .	59.5	72.2	....	101.1	2.13	....	......	2.16	.503	17.1	14

TABLE 32.—*Increase in heat-output of E. D. B. during horizontal walking in experiments without food. (Values per minute.)*—Continued.

Date and condition.	(*a*) Body-weight with clothing.	(*b*) Distance.	(*c*) Horizontal kilogrammeters. $a \times b$	(*d*) No. of steps.	(*e*) Raising of body (step-lift).	(*f*) Work due to step-lift. $a \times e$	(*g*) Total heat.	Increment in heat above standing-value. (*h*) Total increase.	(*i*) Per horizontal kilogrammeter. $\frac{h \times 1{,}000}{c}$	(*j*) Per kilogrammeter of step-lift. $\frac{h \times 1{,}000}{f}$	(*k*) Proportion of increase due to step-lift. $\frac{2.34 \times 100}{j}$
1915. Oct. 25:	*kg.*	*meters.*			*meters.*	*kg. m.*	*cals.*	*cals.*	*gm.-cal.*	*gm.-cals.*	*p. ct.*
Standing...	......	......	....	....	......	....	1.07	......	....	....	....
Walking...	......	72.5	4,278	101.4	2.28	134.52	3.12	2.05	0.479	15.9	15
	......	72.9	4,301	101.1	2.60	153.40	3.22	2.15	.500	14.0	17
	......	73.0	4,307	101.4	2.48	146.32	3.22	2.15	.499	14.7	16
	......	73.7	4,348	101.4	2.59	152.81	3.24	2.17	.499	14.1	17
	......	73.7	4,348	101.4	2.53	149.27	3.27	2.20	.506	14.7	16
Average .	59.0	73.2	....	101.4	2.50	....	......	2.14	.497	14.7	16
Oct. 26:											
Standing...	......	......	....	....	......	....	1.06	......	....	....	....
Walking...	......	72.5	4,234	103.0	2.38	139.00	3.15	2.09	.494	15.0	16
	......	72.2	4,216	101.8	2.50	146.00	3.19	2.13	.505	14.6	16
	......	73.5	4,292	102.4	2.52	147.17	3.25	2.19	.510	14.9	16
	......	72.9	4,257	102.6	2.46	143.66	3.19	2.13	.500	14.8	16
	......	73.2	4,275	102.2	2.50	146.00	3.23	2.17	.508	14.9	16
Average .	58.4	72.9	....	102.4	2.47	....	......	2.14	.503	14.8	16
Oct. 27:											
Standing...	......	......	....	....	......	....	1.07	......	....	....	....
Walking...	......	76.6	4,481	104.2	2.75	160.88	3.22	2.15	.480	13.4	18
	......	77.0	4,505	103.8	2.94	171.99	3.27	2.20	.488	12.8	18
	......	77.3	4,522	104.4	2.92	170.82	3.30	2.23	.493	13.1	18
	......	78.3	4,581	104.6	2.98	174.33	3.38	2.31	.504	13.3	18
	......	78.5	4,592	105.0	2.94	171.99	3.40	2.33	.507	13.5	17
	......	78.6	4,598	105.0	2.95	172.58	3.44	2.37	.515	13.7	17
Average .	58.5	77.7	....	104.5	2.91	....	......	2.27	.498	13.3	18
Oct. 28:											
Standing...	......	......	....	....	......	....	1.08	......	....	....	....
Walking...	......	77.1	4,526	106.6	2.57	150.86	3.23	2.15	.475	14.2	17
	......	77.8	4,567	106.6	2.67	156.73	3.29	2.21	.484	14.1	16
	......	77.8	4,567	105.8	2.83	166.12	3.33	2.25	.493	13.5	17
	......	78.1	4,584	106.4	2.95	173.17	3.36	2.28	.497	13.2	18
	......	78.2	4,590	107.2	2.90	170.23	3.30	2.22	.484	13.0	18
Average .	58.7	77.8	....	106.5	2.78	....	......	2.22	.487	13.6	17
Oct. 29:											
Standing...	......	......	....	....	......	....	1.09	......	....	....	....
Walking...	......	77.1	4,557	104.4	2.97	175.53	3.36	2.27	.498	12.9	18
	......	78.1	4,616	106.1	2.90	171.39	3.33	2.24	.485	13.1	18
	......	78.3	4,628	104.4	2.95	174.35	3.40	2.31	.499	13.2	18
	......	78.5	4,639	104.4	2.99	176.71	3.50	2.41	.520	13.6	17
Average .	59.1	78.0	....	104.8	2.95	....	......	2.31	.501	13.2	18

TABLE 32.—*Increase in heat-output of E. D. B. during horizontal walking in experiments without food. (Values per minute.)*—Continued.

Date and condition.	(*a*) Body-weight with clothing.	(*b*) Distance.	(*c*) Horizontal kilogrammeters. *a* × *b*	(*d*) No. of steps.	(*e*) Raising of body (step-lift).	(*f*) Work due to step-lift. *a* × *e*	(*g*) Total heat.	Increment in heat above standing-value. (*h*) Total increase.	(*i*) Per horizontal kilogrammeter. $\frac{h \times 1,000}{c}$	(*j*) Per kilogrammeter of step-lift. $\frac{h \times 1,000}{f}$	(*k*) Proportion of increase due to step-lift. $\frac{2.34 \times 100}{j}$
1915. Oct. 30:	*kg.*	*meters.*			*meters.*	*kg. m.*	*cals.*	*cals.*	*gm.-cal.*	*gm.-cals.*	*p. ct.*
Standing...	......	......	....	....	......	....	[1]1.08	......	....	....	....
Walking...	......	45.2	2,653	80.0	0.70	41.09	2.42	1.34	0.505	32.6	7
	......	43.5	2,553	81.0	.68	39.92	2.32	1.24	.486	31.1	8
	......	43.1	2,530	79.8	.61	35.81	2.34	1.26	.498	32.4	7
Average .	58.7	43.9	....	80.3	.66	....	......	1.28	.496	32.0	7
Nov. 1:											
Standing...	......	......	....	....	......	....	[1]1.08	......	....	....	....
Walking...	......	44.9	2,649	79.2	.75	44.25	2.33	1.25	.472	28.2	8
	......	44.5	2,626	80.0	.70	41.30	2.31	1.23	.468	29.8	8
	......	43.5	2,567	79.8	.72	42.48	2.32	1.24	.483	29.2	8
Average .	59.0	44.3	....	79.7	.72	....	......	1.24	.474	29.1	8
Nov. 2:											
Standing...	......	......	....	....	......	....	[1]1.08	......	....	....	....
Walking...	......	43.9	2,577	80.8	.73	42.85	2.31	1.23	.477	28.7	8
	......	43.4	2,548	79.4	.72	42.26	2.35	1.27	.498	30.0	8
	......	42.3	2,483	79.4	.64	37.57	2.30	1.22	.491	32.4	7
Average .	58.7	43.2	....	79.9	.70	....	......	1.24	.489	30.4	8
Nov. 3:											
Standing...	......	......	....	....	......	....	[1]1.08	......	....	....	....
Walking...	......	45.4	2,674	80.8	.75	44.18	2.27	1.19	.445	26.9	9
	......	44.7	2,633	80.0	.84	49.48	2.28	1.20	.456	24.2	10
	......	43.4	2,556	95.2	.69	40.64	2.23	1.15	.450	28.3	8
Average .	58.9	44.5	....	85.3	.76	....	......	1.18	.450	26.5	9
Nov. 4:											
Standing...	......	......	....	....	......	....	[1]1.08	......	....	....	....
Walking...	......	53.5	3,119	86.4	1.17	68.21	2.43	1.35	.433	19.8	12
	......	53.2	3,102	86.4	1.11	64.71	2.45	1.37	.442	21.2	11
	......	53.9	3,142	86.6	1.24	72.29	2.54	1.46	.465	20.2	12
Average .	58.3	53.5	....	86.5	1.17	....	......	1.39	.447	20.4	12
Nov. 5:											
Standing...	......	......	....	....	......	....	[1]1.08	......	....	....	....
Walking...	......	46.9	2,739	82.2	.85	49.64	2.32	1.24	.453	25.1	9
	......	46.2	2,698	81.8	.80	46.72	2.32	1.24	.460	26.6	9
	......	45.6	2,663	81.6	.79	46.14	2.32	1.24	.466	26.9	9
Average .	58.4	46.2	....	81.9	.81	....	......	1.24	.460	26.2	9

---

[1] Average of values obtained in experiments without food, with subject standing, October 11 to December 22, 1915, inclusive. (See table 6, page 46.)

Table 32.—*Increase in heat-output of E. D. B. during horizontal walking in experiments without food. (Values per minute.)*—Continued.

Date and condition.	(a) Body-weight with clothing.	(b) Distance.	(c) Horizontal kilogrammeters. $a \times b$	(d) No. of steps.	(e) Raising of body (step-lift).	(f) Work due to step-lift. $a \times e$	(g) Total heat.	Increment in heat above standing-value. (h) Total increase.	(i) Per horizontal kilogrammeter. $\frac{h \times 1{,}000}{c}$	(j) Per kilogrammeter of step-lift. $\frac{h \times 1{,}000}{f}$	(k) Proportion of increase due to step-lift. $\frac{2.34 \times 100}{j}$
1915. Nov. 6:	*kg.*	*meters.*			*meters.*	*kg. m.*	*cals.*	*cals.*	*gm.-cal.*	*gm.-cals.*	*p.ct.*
Standing...	......	......	....	......	......	....	[1]1.08	......	....	....	....
Walking...	......	46.8	2,747	82.0	0.76	44.61	2.24	1.16	0.422	26.0	9
	......	45.8	2,688	80.8	.76	44.61	2.25	1.17	.435	26.3	9
	......	45.0	2,642	79.6	.73	42.85	2.26	1.18	.447	27.5	9
Average .	58.7	45.9	....	80.8	.75	....	......	1.17	.435	26.6	9
Nov. 8:											
Standing...	......	......	....	......	......	....	[1]1.08	......	....	....	....
Walking...	......	55.2	3,257	89.0	1.19	70.21	2.54	1.46	.448	20.8	11
	......	56.1	3,310	88.2	1.32	77.88	2.59	1.51	.456	19.4	12
	......	57.0	3,363	89.8	1.28	75.52	2.59	1.51	.449	20.0	12
Average .	59.0	56.1	....	89.0	1.26	....	......	1.49	.451	20.1	12
Nov. 9:											
Standing...	......	......	....	......	......	....	[1]1.08	......	....	....	....
Walking...	......	54.9	3,228	88.8	1.17	68.80	2.42	1.34	.415	19.5	13
	......	54.5	3,205	87.6	1.16	68.21	2.41	1.33	.415	19.5	13
	......	54.6	3,210	87.6	1.23	72.32	2.46	1.38	.430	19.1	12
Average .	58.8	54.7	....	88.0	1.19	....	......	1.35	.420	19.4	12
Nov. 10:											
Standing...	......	......	....	......	......	....	[1]1.08	......	....	....	....
Walking...	......	48.4	2,846	84.2	.96	56.45	2.27	1.19	.418	21.1	11
	......	47.8	2,811	85.2	1.03	60.56	2.32	1.24	.441	20.4	11
	......	47.1	2,769	84.8	1.02	59.98	2.38	1.30	.469	21.7	11
Average .	58.8	47.8	....	84.7	1.00	....	......	1.24	.443	21.1	11
Nov. 11:											
Standing...	......	......	....	......	......	....	[1]1.08	......	....	....	....
Walking...	......	67.1	3,952	99.0	2.37	139.59	2.78	1.70	.430	12.2	19
	......	68.2	4,017	98.8	2.61	153.73	2.96	1.88	.468	12.2	19
	......	68.4	4,029	99.2	2.39	140.77	2.93	1.85	.459	13.1	18
Average .	58.9	67.9	....	99.0	2.46	....	......	1.81	.452	12.5	19
Nov. 12:											
Standing...	......	......	....	......	......	....	[1]1.08	......	....	....	....
Walking...	......	66.0	3,881	99.2	1.84	108.19	2.84	1.76	.453	16.3	14
	......	67.7	3,981	99.4	1.95	114.66	2.91	1.83	.460	16.0	15
	......	67.6	3,975	98.8	1.96	115.25	2.92	1.84	.463	16.0	15
Average .	58.8	67.1	....	99.1	1.92	....	......	1.81	.459	16.1	15

---

[1] Average of values obtained in experiments without food, with subjects standing, October 11 to December 22, 1915, inclusive. (See table 6, page 46.)

TABLE 32.—*Increase in heat-output of E. D. B. during horizontal walking in experiments without food. (Values per minute.)*—Continued.

Date and condition.	(*a*) Body-weight with clothing.	(*b*) Distance.	(*c*) Horizontal kilogram-meters. *a* × *b*	(*d*) No. of steps.	(*e*) Raising of body (step-lift).	(*f*) Work due to step-lift. *a* × *e*	(*g*) Total heat.	Increment in heat above standing-value.			
								(*h*) Total increase.	(*i*) Per horizontal kilogram-meter. *h* × 1,000 / *c*	(*j*) Per kilogram-meter of step-lift. *h* × 1,000 / *f*	(*k*) Proportion of increase due to step-lift. 2.34 × 100 / *j*
1915. Nov. 13:	*kg.*	*meters.*			*meters.*	*kg. m.*	*cals.*	*cals.*	*gm.-cal.*	*gm.-cals.*	*p. ct.*
Standing...	......	......		......	......	....	[1]1.08	......	....	....	....
Walking...	......	76.1	4,467	104.2	2.61	153.21	3.04	1.96	0.439	12.8	18
	......	76.9	4,514	103.2	2.96	173.75	3.23	2.15	.476	12.4	19
	......	77.0	4,520	104.4	2.67	156.73	3.11	2.03	.449	12.3	19
Average .	58.7	76.7	....	103.9	2.75	....	......	2.05	.455	12.5	19
Nov. 15:											
Standing...	......	......	......	......	......	....	[1]1.08	......	....	....	....
Walking...	......	76.3	4,525	103.0	2.80	166.04	3.15	2.07	.457	12.5	19
	......	77.1	4,572	104.6	2.93	173.75	3.21	2.13	.466	12.3	19
	......	77.5	4,596	104.4	2.77	164.26	3.18	2.10	.457	12.8	18
Average .	59.3	77.0	....	104.0	2.83	....	......	2.10	.460	12.5	19
Nov. 16:											
Standing...	......	......	......	......	......	....	[1]1.08	......	....	....	....
Walking...	......	76.4	4,485	102.8	2.92	171.40	3.19	2.11	.470	12.3	19
	......	77.0	4,520	104.2	2.81	164.95	3.17	2.09	.462	12.7	18
	......	77.4	4,543	104.1	2.97	174.34	3.17	2.09	.460	12.0	20
Average .	58.7	76.9	....	103.7	2.90	....	......	2.10	.464	12.3	19
Nov. 17:											
Standing...	......	......	......	......	......	....	[1]1.08	......	....	....	....
Walking...	......	46.2	2,707	79.0	.86	50.40	2.29	1.21	.447	24.0	10
	......	45.4	2,660	79.0	.75	43.95	2.28	1.20	.451	27.3	9
	......	45.6	2,672	79.0	.74	43.36	2.30	1.22	.457	28.1	8
Average .	58.6	45.7	....	79.0	.78	....	......	1.21	.452	26.5	9
Nov. 18:											
Standing...	......	......	......	......	......	....	1.01	......	....	....	....
Walking...	......	55.7	3,253	90.8	1.32	77.09	2.46	1.45	.446	18.8	12
	......	54.9	3,206	87.4	1.27	74.17	2.39	1.38	.430	18.6	13
	......	54.6	3,189	87.4	1.21	70.66	2.47	1.46	.458	20.6	11
	......	54.9	3,206	88.0	1.10	64.24	2.50	1.49	.465	23.2	10
	......	54.7	3,194	87.8	1.15	67.16	2.51	1.50	.470	22.3	11
Average .	58.4	55.0	....	88.3	1.21	....	......	1.46	.454	20.7	11
Nov. 19:											
Standing...	......	......	......	......	......	....	1.02	......	....	....	....
Walking...	......	76.5	4,468	104.8	2.44	142.50	3.06	2.04	.457	14.3	16
	......	77.7	4,538	104.3	2.49	145.42	3.24	2.22	.489	15.3	15
	......	77.9	4,549	103.0	2.47	144.25	3.19	2.17	.477	15.0	16
	......	78.4	4,579	104.6	2.46	143.66	3.22	2.20	.480	15.3	15
	......	78.9	4,608	104.0	2.31	134.90	3.25	2.23	.484	16.5	14
Average .	58.4	77.9	....	104.1	2.43	....	......	2.17	.477	15.3	15

---

[1] Average of values obtained in experiments without food, with subjects standing, October 11 to December 22, 1915, inclusive. (See table 6, p. 46.)

TABLE 32.—*Increase in heat-output of E. D. B. during horizontal walking in experiments without food. (Values per minute.)*—Continued.

Date and condition.	(a)	(b)	(c)	(d)	(e)	(f)	(g)	Increment in heat above standing-value.			
	Body-weight with clothing.	Distance.	Horizontal kilogrammeters. $a \times b$	No. of steps.	Raising of body (step-lift).	Work due to step-lift. $a \times e$	Total heat.	(h) Total increase	(i) Per horizontal kilogrammeter. $\frac{h \times 1{,}000}{c}$	(j) Per kilogrammeter of step-lift. $\frac{h \times 1{,}000}{f}$	(k) Proportion of increase due to step-lift. $\frac{2.34 \times 100}{j}$
1915.	*kg.*	*meters.*			*meters.*	*kg. m.*	*cals.*	*cals.*	*gm.-cal.*	*gm.-cals.*	*p. ct.*
Nov. 22:											
Standing...							[1]1.08				
Walking...		48.0	2,798	82.2	.79	46.06	2.37	1.29	0.461	28.0	8
		47.3	2,758	80.2			2.37	1.29	.468		
		46.8	2,728	79.8	.79	46.06	2.32	1.24	.455	26.9	9
Average .	58.3	47.4		80.7	.79			1.27	.461	27.5	9
Nov. 23:											
Standing...							[1]1.08				
Walking...		55.5	3,275	89.2	1.18	69.62	2.42	1.34	.409	19.2	12
		53.9	3,180	86.2	1.34	79.06	2.41	1.33	.418	16.8	14
		54.9	3,239	87.8	1.26	74.34	2.43	1.35	.417	18.2	13
Average .	59.0	54.8		87.7	1.26			1.34	.415	18.1	13
Nov. 24:											
Standing...							[1]1.08				
Walking...		57.7	3,399	90.4	1.33	78.34	2.44	1.36	.400	17.4	13
		57.6	3,393	89.6	1.41	83.05	2.46	1.38	.407	16.6	14
		57.1	3,363	90.0	1.37	80.69	2.47	1.39	.413	17.2	14
Average .	58.9	57.5		90.0	1.37			1.38	.407	17.1	14
Nov. 26:											
Standing...							[1]1.08				
Walking...		65.3	3,885	98.2	1.58	94.01	2.72	1.64	.422	17.4	13
		66.2	3,939	99.2	1.55	92.23	2.78	1.70	.432	18.4	13
		66.2	3,939	97.6	1.84	109.48	2.78	1.70	.432	15.5	15
Average .	59.5	65.9		98.3	1.66			1.68	.429	17.1	14
Dec. 1:											
Standing...							[1]1.08				
Walking...		74.9	4,442	105.0	2.52	149.44	3.13	2.05	.462	13.7	17
		76.4	4,531	104.8	2.71	160.70	3.24	2.16	.477	13.4	18
		77.3	4,584	106.2	2.92	173.16	3.18	2.10	.458	12.1	19
Average .	59.3	76.2		105.3	2.72			2.10	.466	13.1	18
Dec. 2:											
Standing...							[1]1.08				
Walking...		71.3	4,214	101.8	2.18	128.84	2.89	1.81	.430	14.1	17
		71.8	4,243	101.8	2.65	156.62	2.93	1.85	.436	11.8	20
		71.8	4,243	101.8	2.63	155.43	2.87	1.79	.422	11.5	20
Average .	59.1	71.6		101.8	2.49			1.82	4.29	12.5	19

---

[1] Average of values obtained in experiments without food, with subject standing, October 11 to December 22, 1915, inclusive. (See table 6, page 46.)

Table 32.—*Increase in heat-output of E. D. B. during horizontal walking in experiments without food. (Values per minute.)*—Continued.

Date and condition.	(*a*) Body-weight with clothing.	(*b*) Distance.	(*c*) Horizontal kilogrammeters. $a \times b$	(*d*) No. of steps.	(*e*) Raising of body (step-lift).	(*f*) Work due to step-lift. $a \times e$	(*g*) Total heat.	Increment in heat above standing-value.			
								(*h*) Total increase.	(*i*) Per horizontal kilogrammeter. $\frac{h \times 1{,}000}{c}$	(*j*) Per kilogrammeter of step-lift. $\frac{h \times 1{,}000}{f}$	(*k*) Proportion of increase due to step-lift. $\frac{2.34 \times 100}{j}$
1915. Dec. 3:	*kg.*	*meters.*			*meters.*	*kg. m.*	*cals.*	*cals.*	*gm.-cal.*	*gm.-cals.*	*p. ct.*
Standing...	......	......	......	......	......	......	[1]1.08	......	......	......	......
Walking...	......	70.5	4,188	103.2	2.39	141.97	2.95	1.87	0.447	13.2	18
	......	71.2	4,229	101.1	2.60	154.44	2.96	1.88	.445	12.1	19
	......	72.1	4,283	101.3	2.69	159.79	2.97	1.89	.441	11.8	20
Average .	59.4	71.3	......	101.9	2.56	......	......	1.88	.444	12.4	19
Dec. 4:											
Standing...	......	......	......	......	......	......	[1]1.08	......	......	......	......
Walking...	......	47.5	2,807	79.4	.99	58.51	2.23	1.15	.410	19.7	12
	......	46.6	2,754	79.2	.91	53.78	2.20	1.12	.407	20.8	11
	......	45.9	2,713	78.4	.89	52.60	2.24	1.16	.428	22.1	11
Average .	59.1	46.7	......	79.0	.93	......	......	1.14	.415	20.9	11
Dec. 6:											
Standing...	......	......	......	......	......	......	[1]1.08	......	......	......	......
Walking...	......	45.2	2,676	78.8	.68	40.26	2.17	1.09	.407	27.0	9
	......	45.1	2,670	78.4	.67	39.66	2.19	1.11	.416	28.0	8
	......	44.7	2,646	78.2	.68	40.26	2.16	1.08	.408	26.8	9
Average .	59.2	45.0	......	78.5	.68	......	......	1.09	.410	27.3	9
Dec. 7:											
Standing...	......	......	......	......	......	......	[1]1.08	......	......	......	......
Walking...	......	43.8	2,593	78.8	.62	36.70	2.24	1.16	.447	31.6	7
	......	43.1	2,552	77.2	.54	31.97	2.20	1.12	.439	35.0	7
	......	50.6	2,996	75.2	.84	49.73	2.37	1.29	.431	26.0	9
Average .	59.2	45.8	......	77.1	.67	......	......	1.19	.439	30.9	8
Dec. 13:											
Standing...	......	......	......	......	......	......	[1]1.08	......	......	......	......
Walking...	......	66.8	3,834	98.6	1.84	105.62	2.63	1.55	.404	14.7	16
	......	66.6	3,823	97.8	2.27	130.30	2.81	1.73	.453	13.3	18
	......	66.7	3,829	96.4	2.09	119.97	2.68	1.60	.418	13.3	18
Average .	57.4	66.7	......	97.6	2.07	......	......	1.63	.425	13.8	17
1916. Jan. 31:											
Standing...	......	......	......	......	......	......	1.16	......	......	......	......
Walking...	......	62.0	3,825	99.0	2.21	136.36	3.20	2.04	.533	15.0	16
	......	63.5	3,918	97.0	2.59	159.80	3.22	2.06	.526	12.9	18
	......	63.4	3,912	94.4	2.59	159.80	3.29	2.13	.544	13.3	18
	......	63.9	3,943	93.4	2.59	159.80	3.22	2.06	.522	12.9	18
Average .	61.7	63.2	......	96.0	2.50	......	......	2.07	.531	18.0	17

---

[1] Average of values obtained in experiments without food, with subject standing, October 11 to December 22, 1915, inclusive. (See table 6, page 46.)

TABLE 32—*Increase in heat-output of E. D. B. during horizontal walking in experiments without food. (Values per minute.)*—Continued.

Date and condition.	(a)	(b)	(c)	(d)	(e)	(f)	(g)	Increment in heat above standing-value.			
	Body-weight with clothing.	Distance.	Horizontal kilogrammeters. $a \times b$	No. of steps.	Raising of body (step-lift).	Work due to step-lift. $a \times e$	Total heat.	(h) Total increase.	(i) Per horizontal kilogrammeter. $\frac{h \times 1{,}000}{c}$	(j) Per kilogrammeter of step-lift. $\frac{h \times 1{,}000}{f}$	(k) Proportion of increase due to step-lift. $\frac{2.34 \times 100}{j}$
1916. Feb. 1:	kg.	meters.			meters.	kg. m.	cals.	cals.	gm.-cal.	gm.-cals.	p. ct.
Standing...	......	......	......	......	......	....	1.29	......	....	....	....
Walking...	......	62.9	3,906	93.4	2.24	139.10	3.19	1.90	0.486	13.6	17
	......	63.2	3,925	94.4	2.28	141.59	3.09	1.80	.459	12.7	18
	......	64.3	3,993	94.8	2.10	130.41	2.95	1.66	.416	12.7	18
	......	63.9	3,968	94.0	2.28	141.59	3.11	1.82	.459	12.8	18
Average .	62.1	63.6	......	94.2	2.23	....	......	1.80	.455	13.0	18
Mar. 20:											
Standing...	......	......	......	......	......	....	1.29	......	....	....	....
Walking...	......	59.5	3,647	......	......	....	2.94	1.65	.452	....	....
	......	60.7	3,721	......	......	....	2.85	1.56	.419	....	....
Average .	61.3	60.1	......	......	......	....	......	1.61	.436	....	....
Mar. 22:											
Standing...	......	......	......	......	......	....	1.22	......	....	....	....
Walking...	......	74.8	4,563	......	......	....	3.32	2.10	.460	....	....
	......	76.9	4,691	......	......	....	3.40	2.18	.465	....	....
Average .	61.0	75.9	......	......	......	....	......	2.14	.463	....	....
Mar. 29:											
Standing...	......	......	......	......	......	....	1.26	......	....	....	....
Walking...	......	57.6	3,502	......	......	....	2.89	1.63	.465	....	....
	......	55.5	3,374	......	......	....	2.85	1.59	.471	....	....
Average .	60.8	56.6	......	......	......	....	......	1.61	.468	....	....
Mar. 30:											
Standing...	......	......	......	......	......	....	1.19	......	....	....	....
Walking...	......	68.5	4,192	......	......	....	3.32	2.13	.508	....	....
	......	63.6	3,892	......	......	....	3.02	1.83	.470	....	....
Average .	61.2	66.1	......	......	......	....	......	1.98	.489	....	....
Mar. 31:											
Standing...	......	......	......	......	......	....	1.19	......	....	....	....
Walking...	......	55.2	3,356	......	......	....	2.69	1.50	.447	....	....
	......	52.9	3,216	......	......	....	2.73	1.54	.479	....	....
Average .	60.8	54.1	......	......	......	....	......	1.52	.463	....	....
Apr. 1:											
Standing...	......	......	......	......	......	....	1.15	......	....	....	....
Walking...	......	53.4	3,257	......	......	....	2.67	1.52	.467	....	....
	......	51.7	3,154	......	......	....	2.61	1.46	.463	....	....
	......	50.4	3,074	......	......	....	2.59	1.44	.468	....	....
Average .	61.0	51.8	......	......	......	....	......	1.47	.466	....	....

Table 32.—*Increase in heat-output of E. D. B. during horizontal walking in experiments without food. (Values per minute.)*—Continued.

Date and condition.	(*a*)	(*b*)	(*c*)	(*d*)	(*e*)	(*f*)	(*g*)	Increment in heat above standing-value.			
	Body-weight with clothing.	Distance.	Horizontal kilogrammeters. $a \times b$	No. of steps.	Raising of body (step-lift).	Work due to step-lift. $a \times e$	Total heat.	(*h*) Total increase.	(*i*) Per horizontal kilogrammeter. $\frac{h \times 1,000}{c}$	(*j*) Per kilogrammeter of step-lift. $\frac{h \times 1,000}{f}$	(*k*) Proportion of increase due to step-lift. $\frac{2.34 \times 100}{j}$
1916.											
Apr. 3:	*kg.*	*meters.*			*meters.*	*kg. m.*	*cals.*	*cals.*	*gm.-cal.*	*gm.-cals.*	*p. ct.*
Standing							1.19				
Walking		35.1	2,152				2.18	.99	0.460		
		35.7	2,188				2.27	1.08	.494		
		36.7	2,250				2.25	1.06	.471		
Average	61.3	35.8						1.04	.475		
Apr. 4:											
Standing							1.13				
Walking		35.9	2,183				2.30	1.17	.536		
		37.0	2,250				2.25	1.12	.498		
		37.0	2,250				2.33	1.20	.533		
Average	60.8	36.6						1.16	.522		
Apr. 5:											
Standing							1.18				
Walking		77.4	4,714				3.53	2.35	.499		
		76.5	4,659				3.42	2.24	.481		
		79.3	4,829				3.51	2.33	.483		
Average	60.9	77.7						2.31	.488		
Apr. 10:											
Standing							1.16				
Walking		78.7	4,832				3.59	2.43	.503		
		77.1	4,734				3.56	2.40	.507		
Average	61.4	77.9						2.42	.505		
Apr. 11:											
Standing							1.16				
Walking		95.9	5,840				4.47	3.31	.567		
		92.0	5,603				4.14	2.98	.532		
		89.0	5,420				4.10	2.94	.542		
Average	60.9	92.3						3.08	.547		
Apr. 12:											
Standing							1.21				
Walking		89.2	5,423				4.34	3.13	.577		
		89.0	5,411				4.18	2.97	.549		
		86.6	5,265				4.04	2.83	.538		
Average	60.8	88.3						2.98	.555		
Apr. 13:											
Standing							1.17				
Walking		99.7	6,072				4.55	3.38	.557		
		97.7	5,950				4.59	3.42	.575		
		94.9	5,779				4.29	3.12	.540		
Average	60.9	97.4						3.31	.557		

TABLE 33.—*Increase in heat-output of J. H. G., E. L. F., and H. M. S. during horizontal walking in experiments without food. (Values per minute.)*

Date and condition.	(*a*) Body-weight with clothing.	(*b*) Distance.	(*c*) Horizontal kilogrammeters. *a* × *b*	(*d*) No. of steps.	(*e*) Raising of body (step-lift).	(*f*) Work due to step-lift. *a* × *e*	(*g*) Total heat.	Increment in heat above standing-value. (*h*) Total increase.	(*i*) Per horizontal kilogrammeter. $\frac{h \times 1{,}000}{c}$	(*j*) Per kilogrammeter of step-lift. $\frac{h \times 1{,}000}{f}$	(*k*) Proportion of increase due to step-lift. $\frac{2.34 \times 100}{j}$
J. H. G.											
1916	*kg.*	*meters.*			*meters.*	*kg. m.*	*cals.*	*cals.*	*gm.-cal.*	*gm.-cals.*	*p. ct.*
Jan. 18;	......	......	......	......	......	......	1.39	......	......	......	......
Standing...	......	55.3	3,832	83.8	1.05	72.8	3.55	2.16	0.564	29.7	8
Walking...	......	55.2	3,825	90.6	1.37	94.9	3.45	2.06	.539	21.7	11
	......	54.5	3,777	90.0	1.52	105.3	3.39	2.00	.530	19.0	12
Average .	69.3	55.0	......	88.1	1.31	......	......	2.07	.544	23.5	10
Jan. 19:											
Standing...	......	......	......	......	......	......	1.29	......	......	......	......
Walking...	......	55.3	3,821	88.9	1.71	118.2	3.31	2.02	.529	17.1	14
	......	55.1	3,807	105.2	1.71	118.2	3.42	2.13	.559	18.9	12
	......	53.8	3,718	108.8	1.54	106.4	3.31	2.02	.543	19.0	12
Average .	69.1	54.7	......	101.0	1.65	......	......	2.06	.544	18.3	13
Jan. 20:											
Standing...	......	......	......	......	......	......	1.33	......	......	......	......
Walking...	......	55.9	3,930	89.7	1.70	119.5	3.33	2.00	.509	16.7	14
	......	55.6	3,909	96.2	1.76	123.7	3.33	2.00	.512	16.2	14
	......	53.5	3,761	105.4	1.67	117.4	3.26	1.93	.513	16.4	14
Average .	70.3	55.0	......	97.1	1.71	......	......	1.98	.511	16.4	14
E. L. F.											
Jan. 21:											
Standing...	......	......	......	......	......	......	1.36	......	......	......	......
Walking...	......	52.5	3,801	90.6	1.71	123.8	3.85	2.49	.655	20.1	12
	......	52.3	3,787	90.4	1.80	130.3	3.39	2.03	.536	15.6	15
	......	52.5	3,801	89.8	1.84	133.2	3.40	2.04	.537	15.3	15
Average .	72.4	52.4	......	90.3	1.78	......	......	2.19	.576	17.0	14
Jan. 22:											
Standing...	......	......	......	......	......	......	1.26	......	......	......	......
Walking...	......	53.6	3,945	96.6	1.98	145.7	3.39	2.13	.540	14.6	16
	......	52.5	3,864	93.2	1.59	117.0	3.40	2.14	.554	18.3	13
	......	52.3	3,849	......	......	......	3.33	2.07	.538	......	......
Average .	73.6	52.8	......	94.9	1.79	......	......	2.11	.544	16.5	14

TABLE 33.—*Increase in heat-output of J. H. G., E. L. F. and H. M. S. during horizontal walking in experiments without food.* (*Values per minute.*)—Continued.

Date and condition.	(*a*) Body-weight with clothing.	(*b*) Distance.	(*c*) Horizontal kilogram-meters. $a \times b$	(*d*) No. of steps.	(*e*) Raising of body (step-lift).	(*f*) Work due to step-lift. $a \times e$	(*g*) Total heat.	Increment in heat above standing-value. (*h*) Total increase.	(*i*) Per horizontal kilogrammeter. $\frac{h \times 1{,}000}{c}$	(*j*) Per kilogrammeter of step-lift. $\frac{h \times 1{,}000}{f}$	(*k*) Proportion of increase due to step-lift. $\frac{2.34 \times 100}{j}$
E. L. F. (Cont.)	*kg.*	*meters.*			*meters.*	*kg. m.*	*cals.*	*cals.*	*gm.-cal.*	*gm.-cals.*	*p. ct.*
Jan. 24:											
Standing...	......	......	......	......	......	....	1.24	......	....	....	....
Walking...	......	49.6	3,576	95.9	1.58	113.9	3.28	2.04	0.570	17.9	13
	......	49.2	3,547	100.8	1.64	118.2	3.24	2.00	.564	16.9	14
	......	48.4	3,490	90.4	1.61	116.1	3.21	1.97	.564	17.0	14
Average .	72.1	49.1	....	95.7	1.61	....	......	2.00	.566	17.3	14
H. M. S.											
Jan. 25:											
Standing...	......	......	......	......	......	....	1.13	......	....	....	....
Walking...	......	44.6	2,944	79.2	1.74	114.8	2.97	1.84	.625	16.0	15
	......	42.2	2,785	76.2	1.68	110.9	2.78	1.65	.592	14.9	16
	......	41.6	2,746	76.0	1.70	110.2	2.79	1.66	.605	15.1	16
Average .	66.0	42.8	....	77.1	1.71	....	......	1.72	.607	15.3	15
Jan. 26:											
Standing...	......	......	......	......	......	....	1.12	......	....	....	....
Walking...	......	53.5	3,520	90.4	2.36	155.3	3.18	2.06	.585	13.3	18
	......	52.7	3,468	77.2	2.34	154.0	3.07	1.95	.562	12.7	18
	......	52.3	3,441	83.2	2.37	155.9	3.04	1.92	.558	12.3	19
Average .	65.8	52.8	....	83.6	2.36	....	......	1.98	.568	12.8	18

In considering the data in tables 29 to 33 for the increment over the standing requirement, it should be remembered that, as explained on page 94, the standing metabolism was not obtained on each day that walking experiments were performed and whenever this was the case, an average value, or a value determined from a series of days nearest the time of the walking experiments, has been used. The selection of the standing values to be used on those days for which it was not determined has been a matter of some difficulty. Thus, H. R. R. on March 20 showed an unusually high standing metabolism. This value has been employed in computing the increase for walking on that day, but it has been considered that probably the measurements found on April 10 and 17 more nearly represent the normal basal metabolism for this man, and the average for these two days has been used in computing the increase on March 27, April 3, and 24, on which there were no standing experiments.

TOTAL INCREMENT IN HEAT-PRODUCTION.

The total increment in the heat-production above the standing requirement is assumed to represent the energy cost of the transportation of the body-weight over a definite distance on the level as expressed in horizontal kilogrammeters. As the amount of this total increment naturally depends upon the speed of walking, the values in column *h* are of but minor interest here, especially as theoretically no work is done in this process and no efficiency value can be computed. It may be noted, however, that for moderate rates of walking, i. e., 50 to 60 meters per minute (approximately 2 miles an hour), the total increase for most of the subjects is a little less than double the standing requirement, with W. K. an apparent exception. E. D. B. shows for speeds of 95 to 100 meters per minute (approximately 4 miles an hour), an increase of nearly three times his requirement when he was standing, while for a speed of 35 meters per minute the increase was about the same as for the standing requirement, or, stated in another way, when the walking was done at a rate of 35 meters per minute, only half of the total energy expended was due to the act of walking.

INCREMENT IN HEAT PER HORIZONTAL KILOGRAMMETER.

The main point of interest in tables 29 to 33 is the increment in the heat per horizontal kilogrammeter, as this shows the energy cost of walking 1 horizontal meter. This is later used to represent the horizontal component in the energy cost of grade walking. These values are given in column *i* of the several tables.

For A. J. O., at a speed of approximately 63 meters per minute, the walking was done at a cost of from 0.416 to 0.501 gram-calorie per horizontal kilogrammeter, with an average value for the three days of 0.454 gram-calorie. (See table 29.)

The data for H. R. R. show a range in the average values for cost per horizontal kilogrammeter from 0.643 gram-calorie on the first day to 0.574 gram-calorie on the last day. The first period of the first day (March 20) was marked by the fact that the largest energy cost for this subject was here found. As noted in the discussion of table 3, the highest standing metabolism for this subject was also found on this day. In spite of this high standing metabolism, the increase for the horizontal walking is greater than on the subsequent days. On the last two days of experimenting, H. R. R. seems to have walked at a less cost per horizontal kilogrammeter, but the data are too limited for the drawing of any conclusions as to the real betterment in this man's ability to walk with a smaller energy outlay as the time progressed.

T. H. H., walking at a rate varying between 63 and 68 meters per minute, had an increase in the energy output per horizontal kilogrammeter ranging between 0.512 gram-calorie on February 25 and 0.637 gram-calorie on April 5. The average increment on this basis for the 7 days was 0.579 gram-calorie. The daily average increase per horizontal kilogrammeter shows, if anything, a tendency to increase on the last 2 days, when the walking was done at a somewhat slower speed. The energy cost for consecutive periods shows no trend in any one direction. It can hardly be said that the subject walked regularly enough to develop any training effect, though it is to be assumed that acquaintance with the routine might have reduced any psychical effect or feeling of novelty.

Of the 15 days during which W. K. walked on a level (see table 31), 13 days were in March, at the beginning of his use as a subject. Since there were no extreme differences in the speed of walking, the range being from 58 to 68 meters per minute on these days, they offer a fairly consecutive record from which comparisons may be expected. The range in the daily cost per horizontal kilogrammeter during March is from 0.574 gram-calorie on March 4 to 0.440 gram-calorie on March 31. (See table 31.) This decrease in the cost might be taken to indicate an improvement but for the fact that the change is very irregular, although as a rule the higher values are found in the first days of the month. Thus, the average for the first 7 days of experimenting in March is 0.516 gram-calorie and for the last 6 days it is 0.480 gram-calorie per horizontal kilogrammeter. It should also be noted that the last day on which W. K. was a subject (June 23), after 4 months of almost daily walking (see also table 15), his average cost per horizontal kilogrammeter was lower than that on any other day, namely, 0.409 gram-calorie. The results of the series might be taken to indicate, on the whole, a decrease in the cost per horizontal kilogrammeter as this man continued his experiments. The average for the entire series of horizontal walking experiments with W. K. shows an expenditure over that for standing of 0.490 gram-calorie per horizontal kilogrammeter.

In the case of E. D. B. the energy cost per horizontal kilogrammeter ranged from 0.603 gram-calorie on October 9, the first day of his walking, to as low as 0.407 gram-calorie on November 24, while the average for the total 61 days is 0.478 gram-calorie. (See table 32.) To study the effect of training, the values for the same speeds have been grouped chronologically in table 34, so that the results for the different days will be comparable. The daily averages for both the total heat-output and the increment per horizontal kilogrammeter are given in this table. For the approximate speed of 55 meters per minute, the speed at which E. D. B. first walked, the cost per horizontal kilogrammeter fell quite consistently from 0.603 gram-calorie on October 9 to 0.407 gram-calorie on November 24. For a speed of 65 meters per minute there is also a fall between October 16 and December 13, though the change is not so great as with 55 meters per minute. The experiments at the speed of 77 meters per minute were first made late in October, and the effect of the training had already taken place to some extent. Moreover, at this speed, the subject was approaching the point which Durig has termed "the maximal efficiency speed," above which the energy cost increases in a faster ratio. In spite of these neutralizing factors, there is evidence of a fall in the energy cost between the end of October and the middle of November. The speed of 45 meters per minute was not used until October 30, but even these values indicate a decrease in the latter part of the series. It seems clear, therefore, that in the early horizontal-walking experiments with E. D. B., lack of practice or training was a factor in the energy requirement. In this connection it should be noted that on January 31, on E. D. B.'s return from a three weeks' recess due to a lame foot, he had a much higher energy cost per horizontal kilogrammeter than at the end of his previous walking experiments. This may be an erratic result, for it may also be noted that on the second day following

TABLE 34.—*Daily values for metabolism of E. D. B., grouped chronologically on the basis of speed, to determine effect of training. (Values per minute.)*

Approximate speed and date.	Total heat-output.	Increase in heat per horizontal kg. m.	Approximate speed and date.	Total heat-output.	Increase in heat per horizontal kg. m.	Approximate speed and date.	Total heat-output.	Increase in heat per horizontal kg. m.
37 meters:	*cals.*	*gm. cal.*	55 meters—	*cals.*	*gm. cal.*	72 meters:	*cals.*	*gm. cal.*
Apr. 3	2.23	0.475	(cont.).			Oct. 22	3.18	0.494
4	2.29	.522	Nov. 8	2.57	.451	23	3.23	.503
45 meters:			9	2.43	.420	25	3.22	.497
Oct. 30	2.36	.496	18	2.47	.454	26	3.20	.503
Nov. 1	2.32	.474	23	2.42	.415	Dec. 2	2.90	.429
2	2.32	.489	24	2.45	.407	3	2.96	.444
3	2.26	.450	Mar. 29	2.88	.468	77 meters:		
5	2.32	.460	31	2.71	.463	Oct. 27	3.34	.498
6	2.25	.435	Apr. 1	2.62	.466	28	3.30	.487
10	2.32	.443	65 meters:			29	3.39	.501
17	2.29	.452	Oct. 16	3.01	.510	Nov. 13	3.12	.455
22	2.35	.461	18	2.96	.483	15	3.18	.460
Dec. 4	2.21	.415	19	3.05	.503	16	3.17	.464
6	2.18	.410	20	3.09	.517	19	3.20	.477
7	2.27	.439	21	3.07	.517	Dec. 1	3.19	.466
55 meters:			Nov. 11	2.89	.452	Mar. 22	3.36	.463
Oct. 9	3.26	.603	12	2.89	.459	Apr. 5	3.48	.488
11	2.99	.559	26	2.76	.429	10	3.57	.505
13	2.93	.539	Dec. 13	2.70	.425	91 meters:		
14	2.85	.527	[1]Jan. 31	3.23	.531	Apr. 11	4.24	.547
15	2.84	.543	[1]Feb. 1	3.08	.455	12	4.19	.555
Nov. 4	2.48	0.447	Mar. 20	2.89	.436	13	4.48	.557
			30	3.17	.489			

[1] After recess of 3 weeks.

the energy expenditure, though slightly above the average, was not in any way exceptional.

From these considerations it may be seen that the value of 0.478 gram-calorie, while representing an average figure for this subject for the 61 days, does not show the energy cost for a trained subject. If we take the values found for December and March, and thereby eliminate the influence of the early data and also the extremely high and low speeds of April, an average value for the energy cost is obtained for E. D. B. of 0.446 gram-calorie. This is much lower than the average value of 0.55 gram-calorie reported by Benedict and Murschhauser[1] in their summary of the work of earlier observers. But in many cases these average values for the earlier observers include experiments performed when the subjects were not in a strictly post-absorptive condition and in a few instances require an assumption of the respiratory quotient. Moreover, different techniques were employed in the various researches. There is, therefore, no reason to believe that the value of 0.478 gram-calorie as an average for an untrained subject over a considerable period or of 0.446 gram-calorie for a trained subject is exceptionally low.

This effect of training finds support in the figures from the report of Benedict and Murschhauser,[2] although the authors themselves do not consider the evidence is sufficient to make any conclusion in the matter. It is seen from their figures that their Subject I had a value of 0.507 gram-calorie as an average for 16 experiments made during a period of 1 month. The average for the 4 last days of this period, however, was 0.488 gram-calorie and for the first 5 days 0.515 gram-calorie. Also, their Subject II in 57 experiments had an average cost per horizontal kilogrammeter of 0.493 gram-calorie[3] but for the first 10 days of his experiments the average value was 0.506 gram-calorie, while for the last 6 days beginning with April 22, which was after 18 days of walking, the average value was 0.481 gram-calorie. These latter days, moreover, are when their subject was walking at a speed near the point of maximal efficiency.

It is to be regretted that there were no horizontal-walking experiments with E. D. B. in the last part of December or the first part of January, when the standing metabolism of this subject was found to have risen to a higher level. (See p. 98.) But the fact that the energy cost per horizontal kilogrammeter for the approximate speeds of 55 to 77 meters per minute was as a rule higher during March or April than during the early part of December (see table 34) indicates that the increase in the metabolism shown by his standing requirements was also apparent in the cost per horizontal kilogrammeter.

---

[1] Benedict and Murschhauser, Carnegie Inst. Wash. Pub. No. 231, 1915, p. 28.

[2] Benedict and Murschhauser, *Ibid.*, p. 79.

[3] Benedict and Murschhauser, *Ibid.*, p. 87.

Of the other three subjects, J. H. G. expended on an average 0.533 gram-calorie per horizontal kilogrammeter, while it cost E. L. F. 0.562 gram-calorie and H. M. S. 0.588 gram-calorie per horizontal kilogrammeter. (See table 33.) These men were entirely untrained and did not walk long enough in these experiments to produce any training effect.

The average cost per horizontal kilogrammeter of walking on a level, i. e., the increment over the standing requirement, irrespective of any training effect and at speeds mostly below 80 meters per minute, is as follows for each of the eight men included in this report: A. J. O., 0.454; H. R. R., 0.618; T. H. H., 0.579; W. K., 0.490; E. D. B., 0.478; J. H. G., 0.533; E. L. F., 0.562; H. M. S., 0.588 gram-calorie, with a general average of 0.538 gram-calorie. The most data were obtained with W. K. and E. D. B., and these men show the lower values. A. J. O., who likewise shows lower values, was also a well-trained subject, but with him there was only a limited amount of data.

The average value of 0.538 gram-calorie for this group of 8 men is very close to the average value of 0.55 gram-calorie quoted by Benedict and Murschhauser in their summary of the work of other investigators previously referred to. Furthermore, taking into consideration the fact that the basal value used by the other investigators was in the majority of cases either a lying or a sitting value, the individual values for the 8 men studied in the present research do not differ widely in range and character from those given by Benedict and Murschhauser[1] in their summary of previous work done on this subject and already referred to. Although the average value for the group agrees with the average for the subjects of other investigators, the averages for the different men show the variations which may be expected for individual subjects. That these variations may be large is seen by comparing the average for the trained subject E. D. B. and the untrained but thoroughly cooperative subject H. M. S., between which there is a difference of nearly 25 per cent.[2]

Effect of Speed upon Metabolism in Horizontal Walking.

In order to show more clearly the influence of the speed of walking upon the various factors observed, the data in tables 8 to 12 have been grouped according to certain arbitrary limits of 5 meters per minute and averaged. These averages are given in table 35, which also includes the total increment and the increment per horizontal kilogrammeter, taken from columns *h* and *i* of tables 29 to 33, grouped and averaged in the same way. These groups of data represent values obtained in from 3 to 37 periods, but in most cases from 8 to 10 periods have been averaged. At times consecutive periods of the same day fall into different groups if by chance the speeds of the different periods on that day are very near the dividing-line. Each group contains as a rule the results of several days which were in many cases quite widely distributed.

---

[1] Benedict and Murschhauser, Carnegie Inst. Wash. Pub. No. 231, 1915, pp. 24–27.

[2] The possible effects of weight and age as factors in this comparison should not be lost sight of, since H. M. S. was thinner than E. D. B., as well as older and taller.

TABLE 35.—*Metabolism during horizontal walking in experiments without food, grouped according to speed of walking. (Average values per minute.)*

Subject and speed, in meters.	No. of periods.	Average distance walked.	No. of steps.	Horizontal kilogrammeters of work done.	Respiration-rate.	Pulmonary ventilation (reduced).	Body-temperature.	Blood-pressure.
A. J. O.:		*meters.*				*liters.*	*°C.*	*mm.*
60 to 65	6	63.0	[1]96.8	4,689	23.8	16.0	....	....
H. R. R.:								
60 to 65	11	60.9	97.1	4,364	17.3	14.8	....	....
65 to 70	4	67.1	103.3	4,932	18.0	16.4	....	....
T. H. H.:								
60 to 65	7	63.2	99.6	3,621	[3]14.2	11.4	....	....
65 to 70	14	67.1	104.1	3,828	14.6	11.4	....	....
W. K.:								
55 to 60...	10	58.3	106.6	2,999	21.3	11.1	....	....
60 to 65...	19	62.9	109.8	3,247	20.8	10.8	....	....
65 to 70...	20	66.6	114.7	3,452	[7]22.4	11.7	....	....
E. D. B.:								
35 to 40..	6	36.2	....	2,212	19.2	11.3	36.90	120
40 to 45..	13	43.8	79.5	2,578	18.7	11.1	....	....
45 to 50..	22	46.3	80.6	2,722	19.5	11.5	....	....
50 to 55..	22	53.7	[10]87.4	3,181	20.7	13.3	[4]37.03	[4]125
55 to 60..	18	56.5	[11]89.7	3,371	20.0	14.5	[4]36.84	[4]124
60 to 65..	30	63.9	[12]96.5	3,840	19.4	14.2	[2]37.18	[17]120
65 to 70..	15	66.8	[11]98.4	3,929	19.9	14.0	[14]37.13	[14]119
70 to 75..	26	72.2	[15]101.6	4,292	19.0	13.9	[14]36.90	[14]122
75 to 80..	37	77.5	[16]104.7	4,584	20.6	15.1	[3]37.12	[3]125
85 to 90..	4	88.5	....	5,380	24.1	18.5	37.25	130
90 to 100..	5	96.0	....	5,849	23.9	20.1	37.28	130
J. H. G.:								
50 to 55...	3	53.9	101.4	....	19.4	16.1	....	....
55 to 60...	6	55.4	92.3	....	18.7	15.5	....	....
E. L. F.:								
45 to 50...	3	49.1	95.7	....	5.4	13.6	....	....
50 to 55...	6	52.6	[1]92.1	....	12.3	14.5	....	....
H. M. S.:								
45 to 50...	3	42.8	77.1	....	17.5	12.1	....	....
50 to 55...	3	52.8	83.6	....	17.3	12.7	....	....

For footnotes, see facing page.

TABLE 35.—*Metabolism during horizontal walking in experiments without food, grouped according to speed of walking.* (*Average values per minute.*)—Continued.

Subject and speed in meters.	Pulse-rate.	Carbon dioxide.	Oxygen.	Respiratory quotient.	Heat-output (computed).			
					Total.	Due to standing.	Increase over standing.	
							Total.	Per h. kg. m.
A. J. O.:		*c. c.*	*c. c.*		*cals.*	*cals.*	*cals.*	*gm.-cal.*
60 to 65...	....	608	712	0.85	3.46	1.31	2.16	0.460
H. R. R.:								
60 to 65...	[2]104	670	833	.80	4.00	1.35	2.64	.605
65 to 70...	110	754	902	.84	4.47	1.39	3.08	.625
T. H. H.:								
60 to 65...	[4]100	559	[3]651	[3].86	3.17	1.11	2.09	.577
65 to 70...	[5]96	579	692	.84	3.36	1.11	2.23	.579
W. K.:								
55 to 60...	[3]75	426	519	.82	2.50	1.10	1.41	.469
60 to 65...	[6]85	447	[10]558	[10].80	2.68	1.08	1.60	.494
65 to 70...	[8]84	493	[7]589	[7].84	2.86	1.13	1.72	.499
E. D. B.:								
35 to 40..	72	393	467	.84	2.26	1.17	1.10	.499
40 to 45..	[9]74	409	466	.88	2.28	1.08	1.20	.467
45 to 50..	[5]68	415	467	.89	2.29	1.08	1.21	.444
50 to 55..	[4]77	449	535	.84	2.59	1.09	1.49	.469
55 to 60..	[4]76	[18]480	563	.85	2.73	1.13	1.61	.476
60 to 65..	[13]95	528	633	.83	3.06	1.15	1.92	.499
65 to 70..	[3]78	516	586	.88	2.87	1.16	1.78	.454
70 to 75..	[13]82	543	648	.84	3.14	1.08	2.07	.482
75 to 80..	[2]85	580	678	.86	3.31	1.09	2.11	.478
85 to 90..	[9]94	705	864	.82	4.17	1.19	2.97	.552
90 to 100..	98	787	901	.87	4.40	1.17	3.22	.554
J. H. G.:								
50 to 55...	[5]98	537	697	.77	3.32	1.34	1.98	.529
55 to 60...	[1]94	558	710	.79	3.40	1.34	2.06	.535
E. L. F.:								
45 to 50...	100	544	674	.81	3.24	1.24	2.00	.566
50 to 55...	89	586	717	.82	3.46	1.31	2.15	.560
H. M. S.:								
45 to 50...	[17]93	451	601	.75	2.85	1.13	1.72	.607
50 to 55...	[14]88	500	652	.77	3.11	1.12	1.98	.568

[1] 5 periods.
[2] 10 periods.
[3] 6 periods.
[4] 4 periods.
[5] 9 periods.
[6] 12 periods.
[7] 19 periods.
[8] 8 periods.
[9] 3 periods.
[10] 18 periods.
[11] 14 periods.
[12] 28 periods.
[13] 7 periods.
[14] 1 period.
[15] 25 periods..
[16] 31 periods.
[17] 2 periods.
[18] 17 periods.

EFFECT OF SPEED UPON TOTAL HEAT-OUTPUT.

Considering first the total heat-output, we find in all cases an increase with each increase in speed, with the single exception of E. D. B. with a speed of 65 to 70 meters per minute. This exception is due rather to the excessive heat-output for the preceding group of values at 60 to 65 meters per minute. Two-thirds of the values at the latter speed were obtained during the early part of this subject's experience with the treadmill, namely, in October, while nearly all of the periods in the group for 65 to 70 meters were taken from experiments in the following months of November and December, when the effect of training had become apparent. This single exception to the effect of increase of speed gives evidence, therefore, of the effect of training in reducing the energy requirement.

Effect of Speed upon Total Increase in Heat-Output.

The energy-output over the standing requirement likewise increases with the increase in speed in much the same manner as was found with the total heat-output. This may be seen in the next to the last column of table 35 and graphically in figure 10. The high values for E. D. B. at 60 to 65 meters per minute, most of which were obtained early in the

Table 36.—*Percentage increase in heat-output of E. D. B. due to walking on a level at various speeds. (Values per minute.)*

Range of speed.	Horizontal kilogram-meters.	Increase in heat over standing requirement.
meters.		*p. ct.*
35 to 40	2,212	94
40 to 45	2,578	111
45 to 50	2,722	112
50 to 55	3,181	137
55 to 60	3,371	142
60 to 65	3,840	167
65 to 70	3,929	153
70 to 75	4,292	192
75 to 80	4,584	194
85 to 90	5,380	250
90 to 100	5,849	275

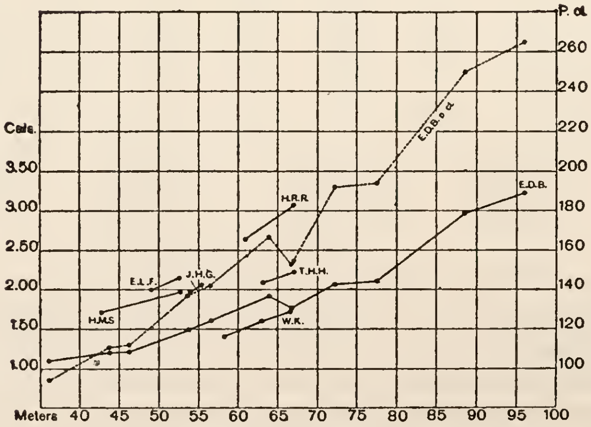

Fig. 10.—Increments in total heat-output over standing requirement for subjects walking on a level at different rates in meters per minute, with percentage increase (broken line) for E. D. B.

study and show lack of training, are also apparent when the data are presented on this basis. The total increase in the heat-output, calculated on the percentage basis, is given for E. D. B. in table 36. These figures show that for slow to medium speeds of walking (35 to 80 meters per minute, that is, not over 3 miles an hour), the per minute increase over the standing requirement ranged from 94 to 194 per cent, while for speeds above 80 meters per minute the percentage increase was from 250 to 275 per cent. These percentage values for the increase in the total heat have also been plotted for E. D. B. in the form of a dotted-line curve, and are included in figure 10.

These increases in the energy-output are given for all of the subjects in table 37 on the basis of per meter increase in speed, and show that for all rates of walking below 80 meters per minute the increase in the heat-output varied on this basis from 0.024 calorie for E. D. B. to 0.071 calorie for H. R. R. The average for the group is 0.041 calorie. It is also seen from the detailed values for E. D. B. that for speeds below 57 meters per minute, each meter increase in speed required an increase in heat of 0.025 calorie, and from 57 to 78 meters per minute, the increase per meter was 0.024 calorie, while for speeds between 78 and 96 meters per minute, the increase per meter was nearly two and one-half times larger, namely, 0.060 calorie.

Table 37.—*Heat-output over standing requirements per 1 meter increase in speed of horizontal walking. (Values per minute.)*

Subject.	Range of average speed.[1]	Increase in speed.	Average increase in total heat-output due to increase in speed.	Average heat increase per meter increase in speed.
	meters.	*meters.*	*cals.*	*cals.*
H. R. R.	60.9 to 67.1	6.2	0.44	0.071
T. H. H.	63.2 to 67.1	3.9	.14	.036
W. K.	58.3 to 66.6	8.3	.31	.037
E. D. B.	36.2 to 77.5	41.3	1.01	.024
J. H. G.	53.9 to 55.4	1.5	.08	.053
E. L. F.	49.1 to 52.6	3.5	.15	.043
H. M. S.	42.8 to 52.8	10.0	.26	.026
Average	52.1 to 62.7	10.7	.34	.041
E. D. B.	36.2 to 56.5	20.3	.51	.025
	56.5 to 77.5	21.0	.50	.024
	77.5 to 96.0	18.5	1.11	.060

[1] See third column, table 35.

Effect of Speed upon Increase in Heat per Horizontal Kilogrammeter.

A summary for all of the subjects of the cost per horizontal kilogrammeter per minute as affected by the speed is given in table 38, in which are included the average results for the two subjects of Benedict and

Murschhauser, grouped according to like speeds. The table shows the wide variations which may be found with different subjects and also that no marked effect on this factor is evident below the speed of 80 to 90 meters per minute (approximately 3 miles an hour). These average values are likewise given in the form of curves for the five principal subjects. (See fig. 11.)

Table 38.—*Average energy cost per horizontal kilogrammeter of walking on a level at different speeds. (Values per minute.)*

Subject.	Energy cost (gm.-cal.) per h. kg. m. at various speeds.										
	35–40 meters.	40–45 meters.	45–50 meters.	50–55 meters.	55–60 meters.	60–65 meters.	65–70 meters.	70–75 meters.	75–80 meters.	85–90 meters.	90–100 meters.
A. J. O.	....	....	....	....	....	0.460	....	....	....	....	....
H. R. R.	....	....	....	....	....	.605	0.625	....	....	....	....
T. H. H.	....	....	....	....	....	.577	.579	....	....	....	....
W. K.	....	....	....	....	0.469	.494	.499	....	....	....	....
E. D. B.	0.499	0.467	0.444	0.469	.476	.499	.454	0.482	0.478	0.552	0.554
J. H. G.	....	....	....	.529	.535	....	....	....	....	....	....
E. L. F.	....	....	.566	.560	....	....	....	....	....	....	....
H. M. S.	....	.607	....	.568	....	....	....	....	....	....	....
Average	0.499	.537	.505	.531	.493	.527	.539	.482	.478	.552	.554
Subject I[1]	....	....	....	....	....	....	.467	.564	.509	....	....
Subject II[1]	....	....	....	....	.521	.498	....	.513	.532	.527	.524

[1] Benedict and Murschhauser, Carnegie Inst. Wash. Pub. No. 231, 1915.

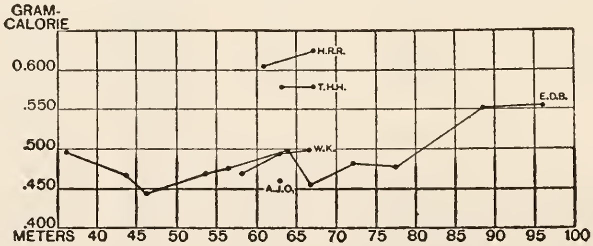

Fig. 11.—Average energy cost per horizontal kilogrammeter of walking on a level at various distances per minute.

From table 38 and figure 11 it is seen that an increase in speed is accompanied by an increase in the cost per horizontal kilogrammeter with H. R. R. and W. K., but practically no change was found for T. H. H. Table 38 also shows practically no change for J. H. G. and E. L. F., but with H. M. S. the cost per horizontal kilogrammeter fell. The curve of E. D. B. as a whole implies that there is practically no increase in the cost per horizontal kilogrammeter for medium speed, but for a speed above 80 to 85 meters per minute the cost increases. The group for the slowest speed, that for 35 to 40 meters per minute, shows a tendency to be higher than the succeeding groups, but these figures are the average of two days in April, while the averages for the two succeeding groups (40 to 45 meters per minute and 45 to 50 meters per minute) were from experiments made in November and December. The lapse of time between these groups is too great, therefore, to permit a statement that the cost increases as the speed falls below a certain comfortable rate of walking.

The effect of speed upon the energy cost per horizontal kilogrammeter can best be shown for E. D. B. by a consideration of the data for March and April, in which there is a wider range of speed and the influence of training is largely eliminated. These results are given in table 39, from which it is evident that for moderate speeds ranging from 55 to 77 meters per minute, the cost per horizontal kilogrammeter shows no tendency to change, but for speeds of 91 meters per minute the cost increased nearly 20 per cent. The latter speed was a forced one and required considerable exertion on the part of E. D. B. to maintain it. This increase in the energy cost is in full agreement with what Durig has claimed, namely, that the cost per horizontal kilogrammeter is practically constant for speeds below 80 to 85 meters per minute, above which speed there is a break in the curve and the energy-output increases at a faster ratio.

TABLE 39.—*Energy cost per horizontal kilogrammeter with E. D. B. of walking on a level at different speeds in March and April 1916. (Values per minute.)*

Date.	Approximate distance walked.	Average heat per h. kg. m.
1916.	*meters.*	*gm.-cal.*
Apr. 3 and 4	37	0.499
Mar. 29, 31, and Apr. 1	55	.466
Mar. 20 and 30	65	.463
Mar. 22, Apr. 5, and 10	77	.485
Apr. 11, 12, and 13	91	.553

In considering the extremely slow speed of 37 meters per minute, it is seen that on the two days of which 0.499 is the average the heat-output was 0.475 and 0.522 gram-calorie per horizontal kilogrammeter, respectively. These values are, unfortunately, not in close agreement. The high value of 0.522 gram-calorie for April 4 might be taken as supporting the statement of Frentzel and Reach,[1] that for slow restrained speeds there is an increase in the heat cost per horizontal kilogrammeter. This claim of Frentzel and Reach has been questioned by Durig,[2] who believes that there is not sufficient evidence in Frentzel and Reach's figures to support their statement. The value of 0.475 gram-calorie for April 3 lies close to the values found for all the other days for speeds up to 78 meters per minute, with the exception of that of April 10, while the value of 0.522 gram-calorie on April 4 finds no support in the data for E. D. B. outside of the early experiments of October and that of January 31, when he resumed walking after an interval of three weeks. (See p. 141.) It seems probable that the value of 0.475 gram-calorie represents more nearly the true condition than does the value 0.522 gram-calorie, in which case it would appear to be in agreement with Durig's statement that there is no increase in the energy cost per horizontal kilogrammeter for slow walking. Obviously a study of the energy demands for extremely slow walking, i. e., sauntering, would be of considerable physiological interest.

---

[1] Frentzel and Reach, Archiv f. d. ges. Physiol., 1901, **83**, p. 494.

[2] Durig, Denkschrift. d. math.-natur. Klasse d. kaiserl. Akad. d. Wissensch., 1909, **86**, p. 271.

Our results do not include those for the highest speeds of walking, as during severe grade walking slow speeds must necessarily be employed. In any consideration of the literature on horizontal walking special attention should certainly be given to the series of experiments of Liljestrand and Stenström,[1] in which the Douglas bag was used. With both subjects, N. S. and G. L., the energy (expressed as oxygen consumption) per horizontal kilogrammeter shows an astonishingly uniform agreement with all of the best earlier work. Since in some instances, at least, the actual duration of these experiments was but 42 seconds, this speaks for not only the great applicability of the Douglas-bag method, but likewise for the extraordinary technical skill of the Swedish investigators. This series of experiments fully substantiates Douglas's conclusions as to the applicability of his bag method to studies of the metabolism during exercise.

Experiments With Subject "Marking Time."

For comparison with the energy requirements of horizontal walking, it seemed of interest to secure a few measurements when the subject simply "marked time," as representing a degree of activity intermediate between standing and walking. Data were therefore obtained with W. K. which are given in table 40. In marking time, the subject kept his legs nearly straight, flexing them as little as possible at the knees. He swung the leg mostly from the hip, thus lifting the body the minimum amount, and although there was some lifting of the limbs, it was not like the regulation marking time of the army. This movement was made at an average rate of 101 so-called "steps" per minute. Under these conditions the average metabolism per minute of W. K. was: carbon dioxide, 414 c. c.; oxygen, 500 c. c.; heat, 2.42 cals.

By consulting table 35, page 144, it is seen that these values correspond very nearly to his requirement for horizontal walking at a speed of 55 to 60 meters per minute, with steps taken at the rate of 106.6 per minute, the heat-output differing only about 3 per cent. It would seem that the energy necessary for horizontal walking is almost wholly confined to that for the muscular effort of the lower limbs, while the oscillations of the trunk in keeping the body balance play a minor rôle. This finds confirmation in some experiments reported by Waller[1] on the carbon-dioxide production during horizontal walking. In a graph showing the carbon-dioxide output for different rates of walking, he also includes that for marking time at a rate of 120 steps per minute. He does not discuss this portion of the curve, and it is probable that the form of marking time was different from that which we used. However, the carbon-dioxide output indicated by his curve seems to be very close to the requirement of the subject when walking at a speed of 92 meters per minute, or 130 steps per minute, viz, an output of 972 c. c. of carbon dioxide for marking time and 960 c. c. for walking. That is, the carbon-dioxide requirement for marking time at 120 steps and walking at 130 steps differed only by 1 per cent.

---

[1] Liljestrand and Stenström, Skand. Archiv f. Physiol., 1920, 39, pp. 178 and 179.

TABLE 40.—*Metabolism of W. K. while "marking time" in experiments without food. (Values per minute).*

Date.	No. of steps.	Average respiration-rate.	Average pulmonary ventilation (reduced).	Average pulse-rate.[1]	Carbon dioxide.	Oxygen.	Respiratory quotient.	Heat-output (computed).
1915.			*liters.*		*c. c.*	*c. c.*		*cals.*
June 3........	92.2	23.3	15.6	74	420	485	0.87	2.37
	97.2	23.3	15.9	74	429	512	.84	2.48
	100.4	23.1	15.3	76	405	487	.83	2.36
	100.4	23.0	15.4	79	416	489	.85	2.38
Average..	97.6	23.2	15.6	76	418	493	.85	2.40
June 4........	99.2	22.9	15.1	74	410	485	.85	2.36
	....	22.0	15.0	74	430	507	.85	2.47
	105.0	22.2	14.8	77	419	500	.84	2.43
	104.2	22.2	14.6	75	409	508	.81	2.45
Average..	102.8	22.3	14.9	75	417	500	.84	2.43
June 5........	102.0	22.1	14.8	75	412	500	.83	2.42
	103.4	21.7	14.3	77	408	515	.80	2.47
	104.4	21.5	14.1	77	401	494	.81	2.38
	104.0	21.8	14.3	78	409	515	.80	2.47
Average..	103.5	21.8	14.4	77	408	506	.81	2.44

[1] See table 27 (page 111) for additional records for pulse-rate of W. K. while he was "marking time."

In their study with army recruits, Cathcart and Orr[2] included observations of the respiratory exchange with a subject "marking time." In 10 experiments after meals of varying composition and with the man carrying loads varying from 5 to 20 kg., the total heat-output varied from 209 to 271 calories per hour. The standing value was about 75 calories per hour.[3] The tempo was 100 beats per minute.

---

[1] Waller, Journ. Physiol., 1919, **53**, Proc. Physiol. Soc., p. xxiv.

[2] Cathcart and Orr, Energy expenditure of the infantry recruit in training. H. M. Stationery Office, London, 1919. (See table 47.)

[3] See subject M, tables 7 and 8 of Cathcart and Orr, *loc. cit.*

They note that the energy cost of "marking time" was with the three greatest loads (16, 21, and 26 kg.) higher than that for slow marching at 62.5 yards (57.2 meters) per minute, and with a load of 11 kg., "marking time" called for almost identically the same energy-output as a slow march of 57.14 meters per minute. A most significant discussion of "marking time" is presented by Cathcart and Orr.[1]

The energy requirement for "marking time" is considerably larger than one would anticipate and shows that unnecessary and extraneous movements might easily lead to considerable differences in the metabolism measurements with muscular work of a moderate degree of intensity. Benedict and Murschhauser[2] have called attention to this in some measurements in which their subject stood and swung his arms and hands as in fast walking, with the result that there was an increase of 126 per cent over his quiet standing metabolism.

Steps and Step-lift During Horizontal Walking.

As was stated in an earlier section (p. 33), a record was kept of the number of steps the subject took in walking, and measurements were frequently made of the height to which the subject lifted his body as a result of the heel-and-toe action in walking. These records are given in detail in tables 29 to 33. The daily averages are summarized according to the speed of walking in table 41, in which the average length of step is also included. It is believed that the number of steps taken is accurately known, and therefore the average length of step is without appreciable error. This can not be so fully claimed, however, for the height of the step-lift, as will be shown later. (See p. 155.)

Table 41.—*Number of steps and height of step-lift in walking on a level.* (*Values per minute.*)

Subject and date.	Distance walked.	No. of steps.	Step-lift.	Step-lift per step.	Length of step.
A. J. O.:	*meters.*		*meters.*	*cm.*	*cm.*
Mar. 2........	62.7	96.8	2.09	2.16	64.8
Feb. 24........	63.5	96.9	1.87	1.93	65.5
H. R. R.:					
Apr. 17........	60.0	98.1	1.05	1.07	61.2
3........	60.5	95.3	1.11	1.16	63.5
24........	60.7	98.3	1.20	1.22	61.7
10........	61.1	99.0	1.02	1.03	61.7
Mar. 20........	66.1	103.8	.92	.89	63.6
27........	66.8	102.6	1.35	1.32	65.1
T. H. H.:					
Apr. 5........	62.8	100.2	1.79	1.79	62.7
Feb. 25........	63.6	99.0	1.61	1.63	64.2
Mar. 30........	65.4	101.3	2.03	2.00	64.6
19........	66.8	106.4	1.73	1.63	62.8
26........	67.2	101.3	2.13	2.10	66.3
22........	67.5	105.8	1.29	1.22	63.8
24........	67.8	104.2	1.83	1.76	65.1

---

[1] Cathcart and Orr, *loc. cit.*, p. 54.

[2] Benedict and Murschhauser, Carnegie Inst. Wash. Pub. No. 231, 1915, pp. 71 and 97.

TABLE 41.—*Number of steps and height of step-lift in walking on a level. (Values per minute.)*—Continued.

Subject and date.	Distance walked.	No. of steps.	Step-lift.	Step-lift per step.	Length of step.
W. K.:	*meters.*		*meters.*	*cm.*	*cm.*
June 23	57.1	106.5	1.28	1.20	53.6
Mar. 18	60.1	104.6	1.01	.97	57.5
16	60.8	108.3	.81	.75	56.1
13	62.1	110.6	1.07	.97	56.1
9	62.3	110.2	.97	.88	56.5
29	62.3	109.3	1.17	1.07	57.0
12	62.5	112.9	1.21	1.07	55.4
4	64.3	114.5	1.27	1.11	56.2
Feb. 26	64.4	114.7	1.40	1.22	56.1
Mar. 31	65.1	108.8	1.18	1.08	59.8
23	65.7	112.1	1.28	1.14	58.6
5	65.8	115.0	1.55	1.35	57.2
8	66.5	116.1	1.49	1.28	57.3
25	67.3	112.7	2.03	1.80	59.7
17	67.5	116.2	1.46	1.26	58.1
E. D. B.					
Nov. 2	43.2	79.9	.70	.88	54.1
Oct. 30	43.9	80.3	.66	.82	54.7
Nov. 1	44.3	79.7	.72	.90	55.6
3	44.5	85.3	.76	.89	52.2
Dec. 6	45.0	78.5	.68	.87	57.3
Nov. 17	45.7	79.0	.78	.99	57.8
Dec. 7	45.8	77.1	.67	.87	59.4
Nov. 6	45.9	80.8	.75	.93	56.8
5	46.2	81.9	.81	.99	56.4
Dec. 4	46.7	79.0	.93	1.18	59.1
Nov. 22	47.4	80.7	.79	.98	58.7
10	47.8	84.7	1.00	1.18	56.4
4	53.5	86.5	1.17	1.35	61.8
Oct. 15	54.4	88.8	1.15	1.30	61.3
14	54.5	88.1	1.34	1.51	61.9
Nov. 9	54.7	88.0	1.19	1.35	62.2
23	54.8	87.7	1.26	1.44	62.5
Oct. 11	55.0	92.9	1.40	1.51	59.2
Nov. 18	55.0	88.3	1.21	1.37	62.3
Oct. 13	55.8	87.0	1.34	1.54	64.1
Nov. 8	56.1	89.0	1.26	1.42	63.0
Oct. 9	57.1	93.0	1.30	1.40	61.4
Nov. 24	57.5	90.0	1.37	1.52	63.9
Jan. 31	63.2	96.0	2.50	2.60	65.8
Feb. 1	63.6	94.2	2.23	2.37	67.5
Oct. 21	63.8	97.3	1.87	1.92	65.6
18	64.3	96.4	1.78	1.85	66.7
19	64.3	96.5	1.83	1.88	66.6
20	64.6	97.6	1.87	1.92	66.2
16	65.0	97.6	1.73	1.77	66.6
Nov. 26	65.9	98.3	1.66	1.69	67.0
Dec. 13	66.7	97.6	2.07	2.12	68.3
Nov. 12	67.1	99.1	1.92	1.94	67.7
11	67.9	99.0	2.46	2.48	68.6
Dec. 3	71.3	101.9	2.56	2.52	70.0
2	71.6	101.8	2.49	2.45	70.3
Oct. 23	72.2	101.1	2.13	2.12	71.4
22	72.3	100.5	2.06	2.05	71.9
26	72.9	102.4	2.47	2.41	71.2
25	73.2	101.4	2.50	2.47	72.2
Dec. 1	76.2	105.3	2.72	2.58	72.4

TABLE 41.—*Number of steps and height of step-lift in walking on a level. (Values per minute.)*—Continued.

Subject and date.	Distance walked.	No. of steps.	Step-lift.	Step-lift per step.	Length of step.
E. D. B.—*Con.*	*meters.*		*meters.*	*cm.*	*cm.*
Nov. 13	76.7	103.9	2.75	2.65	73.8
16	76.9	103.7	2.90	2.80	74.2
15	77.0	104.0	2.83	2.72	74.0
Oct. 27	77.7	104.5	2.91	2.78	74.4
28	77.8	106.5	2.78	2.61	73.1
Nov. 19	77.9	104.1	2.43	2.33	74.8
Oct. 29	78.0	104.8	2.95	2.81	74.4
J. H. G.:					
Jan. 19	54.7	101.0	1.65	1.65	54.2
18	55.0	88.1	1.31	1.49	62.4
20	55.0	97.1	1.71	1.75	56.6
E. L. F.:					
Jan. 24	49.1	95.7	1.61	1.69	51.3
21	52.4	90.3	1.78	1.97	58.0
22	52.8	94.9	1.79	1.79	55.6
H. M. S.:					
Jan. 25	42.8	77.1	1.71	2.22	55.5
26	52.8	83.6	2.36	2.82	63.2

NUMBER OF STEPS IN HORIZONTAL WALKING.

In adapting himself to a definite speed, the subject may either change his length of stride or the number of his steps, and, in fact, he does both. It is to be expected that for slower speeds there will be fewer steps, also that the strides will be shorter; but even for the same speed it is seen that on different days there is a change in both the number and length of steps. This difference amounts in some cases to as much as 6 or 7 steps per minute. W. K., who was the shortest subject, shows the most steps per minute for a given speed, the number of steps at a speed of 67.5 meters being 10 more per minute than the number for T. H. H. at the same speed and 14 more than for H. R .R., the tallest subject, at approximately the same rate of walking. On the other hand, E. D. B., who was shorter than H. R. R., took even fewer steps per minute than the latter, as may be seen by comparing the data for November 26 and December 13 for E. D. B. with those for March 20 and 27 for H. R. R.

These variations make it impossible to draw any definite conclusions even for the same subject. One can only say that a man, walking at normal and constant speed, may unconsciously alter his gait four or more steps per minute, and although the difference between individuals depends in a large measure upon the length of leg of the subjects, it is possible for a shorter man to take natural strides which are longer than those taken by a taller individual. The number of steps represents to a certain degree the amount of effort exerted in walking, but evidently, at least with these subjects and the rates of speed here used, the number does not appear to be proportional to the energy expended.

The average number of steps taken by E. D. B. at different speeds is shown in table 42. (See p. 156.) The increase in the number of steps with greater speed is not regular, but shows a diminishing rate as the speed increases. Thus, the number of steps was 8.4 greater for 55 meters per minute than for 45 meters per minute, or an increase of 0.84 step for each meter per minute increase in speed, and 0.82 step when the speed became 65 meters per minute. The increase to 72 and 77 meters per minute was accompanied by an increase of practically 0.62 per meter increase in speed in each case. With E. D. B., therefore, the increase in the speed of walking appears to have been more nearly taken care of at the lower speeds by an increase in the number of steps, but with the higher speeds this became a lessening factor.

Step-Lift During Horizontal Walking.

In considering the data recorded in tables 29 to 33 for the elevation of the body, or what we have termed the step-lift, it is recognized that there are considerable variations in this factor for the same subject at the same speed on different days, and also that substantial differences appear at times for the same subject in the periods for the same day. This would naturally lead to a questioning of the technique by which the measurements were made.

POSSIBLE CAUSES FOR VARIATION IN STEP-LIFT.

The most apparent fault in the technique which would lead to these differences in the records would be a failure to have the fork of the recording device (see fig. 1, p. 19) held firmly against the shoulder of the subject, thereby not giving the full effect of the step to the counter. It is, of course, possible that an error may have occurred in this way in a few instances, but as it was recognized that such difficulty might occur we were especially careful to be on the watch for it. Another source of error would be in the slipping of the cord on the periphery of the wheel which operated the counter, This would naturally produce too low a registration. This, we know, did occur in a few instances, and in such cases we have made use of the kymograph record in estimating the lift. After such conditions were discovered, it was the practice to rub a little powdered rosin on the cord at the beginning of each period. Even with this precaution and when no slipping was apparent, differences were still found in the elevation. It seems probable, therefore, that this difference was due to the gait of the subject, produced either by more shoulder-motion or by a lateral swaying of the body or by a difference in the absolute lift. It should be recalled that if a subject, while taking 100 steps a minute, lifted his body 1 cm. a step, it would require a displacement of only 2 mm. from any cause to produce a variation of 20 per cent in the final reading. That the subject changed his gait by changing the number and length of his steps has been shown in the preceding section, but how much this change in the measured step-lift is due to one or the other of these causes we do not know. Though these differences make the measurements of less consequence, nevertheless we believe that the values obtained have enough interest to present.

TOTAL STEP-LIFT PER MINUTE.

A survey of the figures in tables 29 to 33 and 41 shows that for the ranges of speed employed the step-lift per minute varied approximately from 1 to 3 meters, and that a tall man like H. R. R. had a total lift per minute of about the same degree as that of a short man like W. K., who had to take more steps to cover the same distance The relation of speed to the step-lift is best shown by the results obtained for E. D. B., with whom a larger amount of data was obtained. (See table 41.)

It may be of interest to note the average values on the basis of speed. This comparison is made for E. D. B. in table 42, in which we find that the average per minute step-lift at 45 meters per minute was 0.77 meter; for 55 meters, 1.27 meters; for 65 meters, 1.99 meters; for 72 meters, 2.37 meters; and for 77 meters, 2.78 meters.

TABLE 42.—*Relationship between step-lift and speed of walking in horizontal-walking experiments without food with E. D. B. (Values per minute.)*

Average speed, in meters.	Range in total step-lift.	Average total step-lift.	Increment in total step-lift per meter increase in speed.	Total step-lift per meter of distance walked.	Average No. of steps.	Average step-lift per step.
	meters.	*meters.*	*cm.*	*cm.*		*cm.*
45	0.66 to 1.00	0.77	....	1.71	80.6	0.96
55	1.15 to 1.40	1.27	5.0	2.31	89.0	1.43
65	1.66 to 2.50	1.99	7.2	3.06	97.2	2.05
72	2.06 to 2.56	2.37	5.4	3.29	101.5	2.34
77	2.43 to 2.95	2.78	8.2	3.61	104.6	2.66

But of special significance is the increment in the total step-lift per minute due to each meter change in speed. In passing from a speed of 45 to 55 meters per minute, the total step-lift per minute increased on the average for each meter increase in speed 5 cm.; from 55 to 65 meters, 7.2 cm.; from 65 to 72 meters (a change in speed of but 7 meters), the increment was 5.4 cm.; and from 72 to 77 meters (a change in speed of only 5 meters), the increase in the total step-lift was 8.2 cm. per meter increase in speed. These increments per meter increase in speed, which are given in table 42, show rather extraordinary irregularity in the values.

Finally, we should observe the step-lift per meter of distance traveled. It is seen that at 45 meters per minute the step-lift was 1.71

cm. per meter; at 55 meters, 2.31 cm.; at 65 meters, 3.06 cm.; at 72 meters, 3.29 cm.; and at 77 meters, 3.61 cm. These values show, therefore, that the step-lift per meter of distance traveled was somewhat less at the lower speeds. This fact is contrary to the evidence in several of our experiments, from which it appeared that the energy expenditure per horizontal kilogrammeter tended to be somewhat greater at the extremely slow speeds. This again emphasizes the importance of studying more in detail the physiology of walking at slow or "sauntering" speeds.

STEP-LIFT PER STEP.

It is possible that the change in number and length of steps to obtain a desired speed might not affect the lift per step and that it would remain relatively uniform. An inspection of the figures for the lift per step in table 41 shows that the same variations are present here that were found in the number of steps and in the total step-lift per minute. Not only are there variations between individuals for the same speed, but for the same individual at the same speeds on different days variations appear which, though not large in themselves, amount to as much as 20 per cent of the total step-lift per minute. Thus W. K., walking at a speed of 62.3 meters per minute, had a step-lift per step on March 9 of 0.88 cm. and on March 29 of 1.07 cm., with a difference of 0.19 cm., or 21 per cent. With the faster speeds, the step-lift is greater when the extreme speeds are compared, but with the slower speeds there are numerous instances when there was a greater step-lift per step than with speeds a few meters faster. In the long series with E. D. B. it appears that all speeds over 70 meters per minute were accompanied by a step-lift per step of 2 cm. or more, and with two exceptions, speeds under 50 meters per minute had a step-lift per step of less than 1 cm. The high values for January 31 and February 1, 1916, fall quite out of the regularity of the series. The conditions involving the individual gaits are apparently too complex for a simple analysis, and only general impressions can be obtained from the measurements.

Table 42 also shows the average step-lift per step for E. D. B. with change in the average speeds. Here, as in the case of the total step-lift per meter distance, there is an absence of uniformity in the amount of increase in the step-lift, though the increase is progressive in each instance.

Energy Increment Due to Work of Step-Lift.

By multiplying the step-lift as given in meters by the body-weight of the subject, it is possible to obtain the kilogrammeters of work done due to this elevation of the body.[1] From this the heat-output per kilogrammeter of step-lift has been computed. (See column *f* of tables 29 to 33.) By using the factor 426.6 for the mechanical equivalent of heat,[1] we may likewise compute the probable proportion of the increment in the heat-output which was due to the work of the step-lift. These percentages are given for each experiment in the last column of tables 29 to 33, in which 2.34 gram-calories is taken as the heat equivalent of 1 kg. m.

---

[1] It is most important to note that the effort of sustaining and lowering the body is entirely disregarded in this calculation.

Thus, by reference to table 29, we find that A. J. O., with a body-weight of 75 kg. and walking at a speed of 63.1 meters per minute, accomplished on February 24 in the first period 4,733 h. kg. m. per minute, and by his steps lifted his body to an elevation of 1.72 meters in 1 minute, thus performing 129 kg. m. of work. His standing basal metabolism for this day was 1.30 calories per minute. His walking metabolism for this period was 3.67 calories. The increase due to the walking was therefore 2.37 calories, which is equivalent to 0.501 gram-calorie per horizontal kilogrammeter, and 18.4 gram-calories per kilogrammeter of work for the step-lift.

The values for the energy cost of this work of lifting the body (see column *j*, tables 29 to 33) show expenditures from as high as 47 gram-calories per kilogrammeter for H. R. R. to as low as 12 gram-calories for E. D. B. The average cost per kilogrammeter of step-lift for A. J. O. is 15.3 gram-calories, with a percentage of increment due to the elevation of the body of 14 to 17 per cent. The percentage of increment for H. R. R. is as low as 5 per cent on his first day of walking and does not exceed 8 per cent at other times. With T. H. H. the average cost per kilogrammeter due to step-lift was 22.1 gram-calories, and the average percentage of increment 11 per cent.

The values for W. K. show considerable variation, the elevation of the body ranging in the periods between 0.7 and 2.07 meters per minute, with the amount of work done varying between 36.8 and 104.5 kilogrammeters. The least amount of work done was on March 16, and these values are so much less than the other values for this subject that they may fairly be questioned. The original records show nothing, however, to indicate any defect in the technique to account for this variance. The average heat-output per kilogrammeter due to step-lift was 25.5 gram-calories, with considerable variation from day to day. The daily average for the percentage of increment due to step-lift ranged from 6 per cent on March 16 to 14 per cent on March 25. The average for the first 6 days in March was 9 per cent and of the last 6 days 10 per cent, but this difference is not sufficient to imply any improvement in this respect, as these figures can at best be considered as only approximate.

---

[1] Armsby, Principles of animal nutrition, New York, 2d ed., 1906, p. 233. A so-called "best" value of 426.7 is reported in the Smithsonian Physical Tables, Washington, 1920, 7th rev. ed., table 212, p. 197. Our computations were made previous to the publication of this edition by means of the slightly lower figure.

For the subjects as a group, with walking at average speeds, the percentage increments due to step-lift range usually from 8 to 14 per cent, while with higher speeds a value for E. D. B. was found of 18 or 19 per cent. Benedict and Murschhauser[1] report a step-lift of 3.78 meters for their Subject I while he was walking at a speed of 75.9 meters per minute. Since his body-weight was 73.1 kg., this corresponded to a work equivalent of 276.32 kilogrammeters, or an energy requirement of 0.65 calorie per minute, which was approximately 23 per cent of the total energy increment due to walking. This value is much higher than that found for any of our subjects, the nearest approach to it for similar speed being that for E. D. B., who, on December 1, walked at a speed of 76.2 meters per minute, with a step-lift of 2.72 meters per minute, using 18 per cent of the heat expended for horizontal progression in the step-lift.

TABLE 43.—*Effect of training on step-lift and on proportion of heat-output expended in such movement. Subject, E. D. B., horizontal-walking experiments without food. October 30, 1915, to February 1, 1916. (Values per minute.)*

Date and speed.	Average step-lift.	Proportion of increase in heat due to step-lift.
43 to 48 meters:	*meters.*	*p. ct.*
Oct. 30....	0.66	7
Nov. 1....	.72	8
2....	.70	8
3....	.76	9
5....	.81	9
6....	.75	9
10....	1.00	11
17....	.78	9
22....	.79	9
Dec. 4....	.93	11
6....	.68	9
7....	.67	8
52 to 58 meters:		
Oct. 9....	1.30	9
11....	1.40	11
13....	1.34	10
14....	1.34	11
15....	1.15	9
Nov. 4....	1.17	12
8....	1.26	12
9....	1.19	12
18....	1.21	11
23....	1.26	13
24....	1.37	14
60 to 68 meters:	*meters.*	*p. ct.*
Oct. 16....	1.73	12
18....	1.78	14
19....	1.83	13
20....	1.87	13
21....	1.87	13
Nov. 11....	2.46	19
12....	1.92	15
26....	1.66	14
Dec. 13....	2.07	17
Jan. 31....	2.50	17
Feb. 1....	2.23	18
71 to 73 meters:		
Oct. 22....	2.06	14
23....	2.13	14
25....	2.50	16
26....	2.47	16
Dec. 2....	2.49	19
3....	2.56	19
76 to 78 meters:		
Oct. 27....	2.91	18
28....	2.78	17
29....	2.95	18
Nov. 13....	2.75	19
15....	2.83	19
16....	2.90	19
19....	2.43	15
Dec. 1....	2.72	18

The effect of training on the step-lift and on the heat-output due to this factor may be studied by reference to table 43, in which have been grouped the average step-lift per day for various speed groups and also the percentage of the heat-output expended due to this step-lift. An inspection of these figures shows no uniform change in the step-lift for a definite speed as the experiments continued, except possibly with the 60 to 68 meter group. In several groups, the percentage of the increment in the heat-output due to the step-lift increased somewhat as time progressed. As has already been seen in other groupings of the results, these figures show that as the speed increased, the step-lift also increased, likewise the percentage of the increment in heat due to the step-lift.

---

[1] Benedict and Murschhauser, Carnegie Inst. Wash. Pub. No. 231, 1915, p. 80.

The above consideration of the step-lift suggests several important lines of study, for if the step-lift involves a minimum of from 10 to 20 per cent of the energy required above basal for the work of forward progression, it can readily be seen that a type of gait which would minimize the step-lift would tend to decrease this factor. Doubtless the time relations of elevation, sustained suspension, and lowering of the body in typical and atypical gaits would throw much light on this important problem of efficient and economical horizontal walking. That such a study should likewise consider the gait in grade walking is obvious. It is the current practice of experienced mountaineers to alter their gait frequently.

Physiological Effects of Horizontal Walking.

As was done in the standing experiments, records were obtained in these walking experiments of the respiration-rate, pulmonary ventilation, pulse-rate, and, in some of the experiments, especially with E. D. B., the body-temperature and blood-pressure. The detailed records are given in the statistical tables 8 to 12, and the daily averages grouped according to speed in table 35. A summary is also given in table 44, in which not only the averages for the speed groups are given, but also the number of experimental periods on which the speed-group data are based, and the increments due to the activity of walking. These increments have been calculated by using as a basal value for each subject the average of the values obtained in his standing experiments. (See tables 3 to 7.)

Respiration-Rate During Horizontal Walking.

From tables 8 to 12, and 35, and the summary in table 44, it is seen that individual subjects show wide individual differences. For the same subject the increase in the respiration-rate for the moderate speeds of walking was gradual and no larger than the variations in the results for an individual with a definite speed. This applies with E. D. B. up to an average speed of 77.5 meters per minute, but above this speed the respiration-rate increased more rapidly. Thus, the increment above the standing rate was increased 1.9 respirations for an increase in average speed from 43.8 to 77.5 meters per minute, while with an increase in speed from this point to 96.0 meters per minute, the increment in the respiration over the standing increased 3.3 respirations.

The respiration-rate of E. L. F. was of marked peculiarity on the two days of January 22 and 24 as compared with the rate on January 21. (See table 12, p. 68.) On all three days the respiration tracings shown on the kymograph for the standing periods were normal and not dissimilar to those of the other subjects. This was also the case with his walking periods on January 21, but in his walking periods of January 22 and 24 there was a marked change, the rates falling to 5 to 8 per minute, while the volume per respiration (unreduced), as meas-

Table 44.—*Increments in various physiological factors due to walking on a level in experiments without food. (Values per minute.)*

Subject and speed.	No. of experimental periods.	Average distance walked.	Respiration-rate.		Pulmonary ventilation (reduced).	
			Average.	Increase over standing.	Average.	Increase over standing
A. J. O.:		*meters.*			*liters.*	*liters.*
60 to 65 meters..	6	63.0	23.8	2.0	16.0	8.2
H. R. R.:						
60 to 65 meters..	11	60.9	17.3	1.8	14.8	7.8
65 to 70 meters..	4	67.1	18.0	2.5	16.4	9.4
T. H. H.:						
60 to 65 meters..	7	63.2	14.2	1.3	11.4	4.9
65 to 70 meters..	14	67.1	14.6	1.7	11.4	4.9
W. K.:						
55 to 60 meters..	10	58.3	21.3	.2	11.1	4.6
60 to 65 meters..	19	62.9	20.8	−.3	10.8	4.3
65 to 70 meters..	20	66.6	22.4	1.3	11.7	5.2
E. D. B.:						
35 to 40 meters.	6	36.2	19.2	3.8	11.3	2.2
40 to 45 meters.	13	43.8	18.7	3.3	11.1	2.0
45 to 50 meters.	22	46.3	19.5	4.1	11.5	2.4
50 to 55 meters.	22	53.7	20.7	5.3	13.3	4.2
55 to 60 meters.	18	56.5	20.0	4.6	14.5	5.4
60 to 65 meters.	30	63.9	19.4	4.0	14.2	5.1
65 to 70 meters.	15	66.8	19.9	4.5	14.0	4.9
70 to 75 meters.	26	72.2	19.0	3.6	13.9	4.8
75 to 80 meters.	37	77.5	20.6	5.2	15.1	6.0
85 to 90 meters.	4	88.5	24.1	8.7	18.5	9.4
90 to 100 meters.	5	96.0	23.9	8.5	20.1	11.0
J. H. G.:						
50 to 55 meters..	3	53.9	19.4	3.1	16.1	5.5
55 to 60 meters..	6	55.4	18.7	2.4	15.5	4.9
E. L. F.:						
45 to 50 meters..	3	49.1	5.4	−9.6	13.6	3.0
50 to 55 meters..	6	52.6	12.3	−2.7	14.5	3.9
H. M. S.:						
45 to 50 meters..	3	42.8	17.5	.6	12.1	2.1
50 to 55 meters..	3	52.8	17.3	.4	12.7	2.7

Table 44.—*Increments in various physiological factors due to walking on a level in experiments without food.* (*Values per minute.*)—Continued.

Subject and speed.	Pulse-rate.		Body-temperature.		Blood-pressure.	
	Average	Increase over standing.	Average.	Increase over standing.	Average.	Increase over standing.
A. J. O.:			°*C.*	°*C.*	*mm.*	*mm.*
60 to 65 meters..	...	...	...	...	...	...
H. R. R.:						
60 to 65 meters..	104	11	...	...	...	...
65 to 70 meters..	110	17	...	...	...	...
T. H. H.:						
60 to 65 meters..	100	4	...	...	...	...
65 to 70 meters..	96	0	...	...	...	...
W. K.:						
55 to 60 meters..	75	−4	...	...	...	...
60 to 65 meters..	85	6	...	...	...	...
65 to 70 meters..	84	5	...	...	...	...
E. D. B.:						
35 to 40 meters.	72	−6	36.90	0.01	120	3
40 to 45 meters.	74	−4	...	...	...	...
45 to 50 meters.	68	−10	...	...	...	...
50 to 55 meters.	77	−1	37.03	.14	125	8
55 to 60 meters.	76	−2	36.84	−.05	124	7
60 to 65 meters.	95	17	37.18	.29	120	3
65 to 70 meters.	78	0	37.13	.24	119	2
70 to 75 meters.	82	4	36.90	.01	122	5
75 to 80 meters.	85	7	37.12	.23	125	8
85 to 90 meters.	94	16	37.25	.36	130	13
90 to 100 meters.	98	20	37.28	.39	130	13
J. H. G.:						
50 to 55 meters..	98	−12	...	...	...	...
55 to 60 meters..	94	−16	...	...	...	...
E. L. F.:						
45 to 50 meters..	100	−7	...	...	...	...
50 to 55 meters..	89	−18	...	...	...	...
H. M. S.:						
45 to 50 meters..	93	1	...	...	...	...
50 to 55 meters..	88	− 4	...	...	...	...

ured by the kymograph tracings, was increased to not far from 3 liters per respiration or approximately three times that of the average for the other subjects. The respiration-rates in the last two days were undoubtedly abnormal, although E. L. F. reported that he was unconscious of making any effort and was not aware of breathing other than normally. He thought that once during the experiment his throat felt rather dry, and stated that at one time he had been troubled with asthma.

Pulmonary Ventilation During Horizontal Walking.

The data in tables 8 to 12 show that the pulmonary ventilation for a given speed was fairly uniform, also that there was no marked change from period to period during the day. The percentage increases over the average standing rate for the various speed groups are given for

E. D. B. in table 45. The average percentage changes in the ventilation for all of the subjects, as calculated for approximately the same speed, i. e., 52.6 to 63.2 meters per minute, are likewise given in table 45. It is apparent from these percentages that the differences between the individual subjects are very great. Even if we exclude those subjects for whom we have the least data and compare the results for W. K. and E. D. B., with whom the greatest number of experiments were made, we still find a range of from 59 to 71 per cent for practically the same speed of walking.

The effect of the increase in speed upon the ventilation for the individual subjects can be seen from the group averages in table 44. H. R. R. shows an increase, T. H. H. shows no change, while with W. K. there was a slight increase. With E. D. B. there was practically no change for the three lower speeds; for the speeds between 56.5 and 72.2 meters per minute there was an increase over the preceding groups, but within this range the ventilation was quite constant, while above this speed the rate of increase was much greater. This is seen in table 45, in which the increase in the ventilation over the standing is figured percentagewise for this subject for the various speed-groups given in table 44. The slight difference in the percentage for the moderate speeds with the marked increase for speeds above 77.5 meters is here very apparent.

Table 45.—*Percentage increase in pulmonary ventilation over standing requirement with E. D. B., at increasing speeds of horizontal walking, and for all subjects at approximately the same speed (53 to 63 meters). (Values per minute.)*

Subjects.	Average speed.	Percentage increase over standing.	Subjects.	Average speed.	Percentage increase over standing.
	meters.	*p. ct.*		*meters.*	*p. ct.*
E. D. B....	36.2	24	A. J. O....	63.0	100
	43.8	22	H. R. R....	60.9	80
	46.3	26	T. H. H....	63.2	75
	53.7	46	W. K......	58.3	71
	56.5	59	E. D. B....	56.5	59
	63.9	56	J. H. G....	53.9	52
	66.8	54	E. L. F....	52.6	37
	72.2	53	H. M. S....	52.8	27
	77.5	67			
	88.5	103			
	96.0	122			

Pulse-Rate During Horizontal Walking.

The belief that there is a relationship between the pulse-rate and the degree of metabolism for the same subject has been expressed in previous reports from this Laboratory,[1] and for a number of years it has been the practice to record carefully the pulse-rates in all the basal metabolism measurements carried out here. Such records were accordingly made in this research.

---

[1] Benedict and Cathcart, Carnegie Inst. Wash. Pub. No. 187, 1913, pp. 153 and 172; Benedict and Murschhauser, Carnegie Inst. Wash. Pub. No. 231, 1915, p. 69; Harris and Benedict, Carnegie Inst. Wash. Pub. No. 279, 1919, p. 79.

The detailed data of the pulse-rates of the subjects during the horizontal walking periods, as obtained by the method already described, are given chronologically in tables 8 to 12. It should be stated again, however, that the difficulties which were experienced in this initial work of recording the pulse-rate have made the data incomplete. Accordingly, although the rates as reported for the individual periods are, in a large majority of cases, average values determined at three intervals about equally distributed throughout the period, nevertheless, there are individual averages which represent only one or two readings.

As the pulse-rates tended to increase during the walking periods, the average value would naturally be affected by the failure to secure either the first or the last reading, and this fact undoubtedly explains some of the irregularities. Although many measurements of the pulse-rate have been made in connection with studies on muscular exercise, the difficulties of actually recording the pulse by the methods commonly used are great when the subject is exercising, and most of the records previously reported have therefore been made immediately at the end of and not during the period of exercise.[1]

As the pulse-rate is subject to sudden and wide fluctuations due to mental and physical conditions, uniformity in results is perhaps more than should be expected, and only comparisons from much larger groups of results than here obtained could yield very definite conclusions. For this reason the speed groups in table 35 and the summary in table 44 give, perhaps, the most satisfactory method for comparing the material at hand. However, the results recorded in tables 8 to 12 show one point very clearly, namely, that the pulse-rates tended to increase as the periods continued during the forenoon.

From both tables 35 and 44 it may be seen that H. R. R. had a high pulse-rate as compared with other men walking at similar speeds. With this subject the highest pulse-rate and highest metabolism were obtained on his first day of walking. (See table 8, p. 56.) The two averages for H. R. R. in tables 35 and 44 show that his pulse-rate was increased 6 beats for an average increase in speed of 6.2 meters per minute. T. H. H., however, shows the reverse, although the average for the heat-output increased. (See table 35.) W. K. had an increase in pulse-rate between the first and second speed-groups, but a drop of 1 beat between the second and third groups. These figures of W. K. do not cover the earlier days of his walking experiments, while the average speeds, as well, indeed, as the average metabolism (see table 35), are from the full quota of experiments. The relationship is but little changed, however, if the speed and metabolism averages are based on the same days for which the pulse-records are available. The variations which may occur in the pulse-rates for the same subject are seen by comparing the rates of W. K. for March 17 and 25. The speed of walking on these days was almost identical and the period pulse-rates on each day were uniform, and yet there is a difference between the pulse-rates on the two days of 17 beats per minute. (See table 10, p. 58.)

---

[1] A striking exception is that too little known but admirable research of W. P. Bowen (Bowen, A study of the pulse-rate in man as modified by muscular work. Contributions to Medical Research, dedicated to Victor Clarence Vaughan by colleagues and former students of the Department of Medicine and Surgery of the University of Michigan, Ann Arbor, Michigan, June, 1903, p. 462.)

With E. D. B. it is seen from table 44 that with the lower speeds of the first three groups the average pulse-rate is 71 and for the next two groups with higher speed the average is 77. Omitting the group for 60 to 65 meters per minute, we find that the three speed-groups from 65 to 80 meters per minute have an average pulse-rate of 82, and the last two groups an average pulse-rate of 96. Thus, when the subject changed from the lowest average speed of 36.2 meters per minute to an average of 77.5 meters per minute, with an increase in distance walked of 41 meters per minute, the increment in the pulse-rate was but 13 beats, whereas a further increase in speed of only 19 meters per minute produced exactly the same increment in the pulse-rate, i. e., 13 beats. This marked change in rate of increase of the pulse at 80 to 85 meters per minute as a result of increase in speed is in keeping with the increment found in the total heat-output for walking above this optimum speed.

The high pulse-rate for the group 60 to 65 meters per minute is due to the pulse-records for January 31 and February 1, which, it will be recalled, were the first days following the return of E. D. B. from his absence on account of his lameness. In this group is one record on March 30 of a pulse-rate of 82, which is more in conformity with the pulse-rates of contiguous speed-groups, although this value is still somewhat high. With the three subjects, J. H. G., E. L. F., and H. M. S., there is a *fall* in the average pulse-rate with the *increase* in the speed of walking. This is probably due to the fact that the subjects were untrained and that the lower speeds were ordinarily used on the first day, when a greater mental stimulus would naturally produce a higher pulse-rate. The fact, therefore, that these three men all showed a lowering of the pulse-rate with increase in speed is not, under the circumstances, so significant.

COMPARISON OF PULSE-RATE DURING STANDING WITH THAT DURING HORIZONTAL WALKING.

The effect upon the pulse-rate of the activity of level walking, as obtained from a comparison of these group averages with the standing average, may be seen in table 44. With the lower speeds of W. K. and E. D. B. and in all but one instance with the three laboratory men,

J. H. G., E. L. F., and H. M. S., at similar speeds, *the pulse-rate during walking was lower than in the standing periods.* The difference is in many cases pronounced and implies that even with a trained subject like E. D. B. it is possible to have a lower pulse during moderate walking than when standing. If, instead of using the average group values, the pulse-rates on the days when both standing and horizontal walking experiments were successively made are compared by plotting the continuous pulse-readings during the forenoon, the relationship between standing and walking values will be more clearly shown. A few curves for W. K. and E. D. B. have been plotted in figure 12. Here it is seen that whereas the pulse-rate tended to increase during the walking periods, during the standing periods there was considerable variation; also, that as a rule the increase was marked when the subject changed

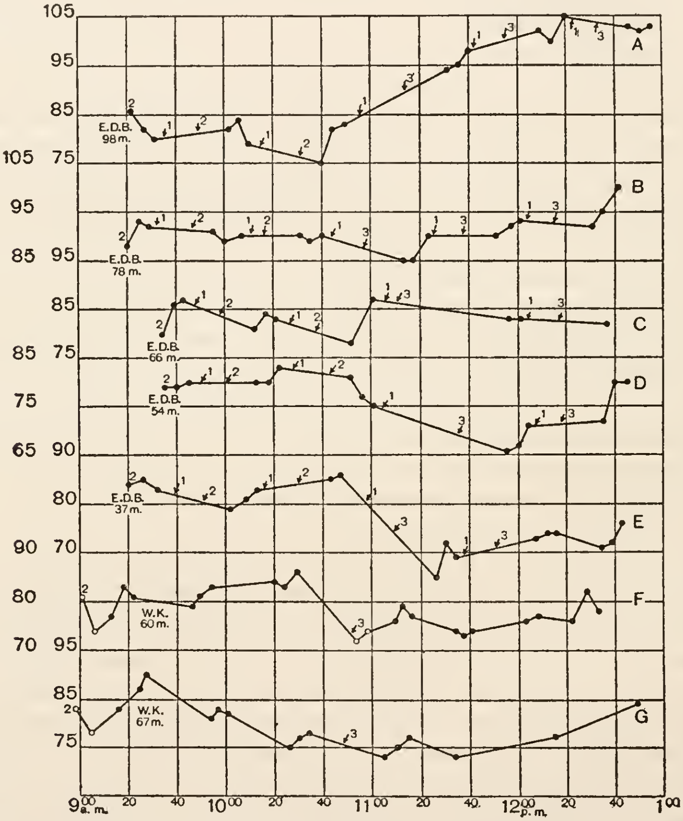

FIG. 12.—Typical pulse-rate curves for E. D. B. and W. K. during standing and horizontal-walking experiments. (Values per minute.)

Speed of walking indicated in meters. Change of conditions shown by arrows and numbers: 1, subject sitting; 2, standing; 3, walking. Records made in the experimental periods represented by black points. Curve *A*, April 13; *B*, April 5; *C*, March 30; *D*, March 31; *E*, April 4, 1916; *F*, March 18; *G*, March 17, 1915.

from standing to walking, although the reverse was sometimes true. The most striking point is the wide difference in the pulse-rate which may be expected from the same subject, even when the conditions are practically the same. It would appear as though the pulse is so sensitive and variable, not only from day to day, but from minute to minute, that any uniform figures are not to be expected, and even with the use of experienced and well-trained subjects the conditions of the experiments must be carried out with the least possible opportunity for mental disturbance during the time of the experiment.

In a recent study in the Nutrition Laboratory,[1] some pulse measurements were made with a group of 12 normal young men, both while they were standing and while they were walking on a level at a rate of 70 meters per minute. The average standing value for this group was 79 pulse-beats per minute, while for walking the average rate varied from 88 to 85 beats between the first and twelfth minutes of walking. The standing pulse-rates of W. K. and E. D. B. are thus in keeping with this group average for standing, while the rates for walking at this speed are somewhat lower. In the case of the group of 12 men, it can not be said that the subjects were particularly trained for these experiments, though they were physically active and athletic young men.

Benedict and Murschhauser[2] report that on two days their subject showed a lower pulse-rate during level walking than in the standing portion of the experiment, in spite of the fact that the metabolism was increased over 100 per cent above the basal requirements. This observation was so contrary to the general relation between the pulse-rate and the metabolism that further tests were made at the Nutrition Laboratory and similar results found. In later work[3] with a group of 5 normal men this observation was not confirmed.

In a careful study of the records of W. K. and E. D. B. in the present research and the exclusion of all cases in which there might appear to be some disturbing influence which produced an unduly high pulse-rate for the standing position, we have found the instances given in table 46 of pulse-rates that are lower during level walking at moderate speed than during the preceding time when the subject was standing. Thus, W. K., during the standing period on March 16, in three counts from $9^h\ 7^m$ a. m. to $9^h\ 19^m$ a. m., had a pulse-rate ranging from 77.7 to 84.1 beats. The subject began walking at $10^h\ 45^m$ a. m. at a speed of 59 meters per minute. After he had walked 14 minutes, his pulse-rate was 72.7 and later 74.5. In this particular instance, the records for standing were obtained in the first period of the experiment, while those for walking were for the fourth period on that day; for the intervening

---

[1] Benedict, Miles, Roth, and Smith, Carnegie Inst. Wash. Pub. No. 280, 1919, p. 442.

[2] Benedict and Murschhauser, Carnegie Inst. Wash. Pub. No. 231, 1915, pp. 54, 55, and 85.

[3] Benedict, Miles, Roth, and Smith, Carnegie Inst. Wash. Pub. No. 280, 1919, p. 451.

Table 46.—*Records showing decrease in pulse-rate of W. K. and E. D. B. in changing from standing position to horizontal walking in experiments without food.* (*Values per minute.*)

Subject, date, and time.	Conditions, and rate of walking per minute.	Pulse-rate.
W. K.		
Mar. 16:		
9^{h}07^{m} a. m.	Standing	77.7
9 12 a. m.	Do.	84.1
9 19 a. m.	Do.	81.9
10 45 a. m.[1]	Walking began; 59 meters.	
10 59 a. m.	Walking	72.7
11 04 a. m.	Do.	74.5
Mar. 17:		
10^{h}26^{m} a. m.	Standing	74.8
10 30 a. m.	Do.	77.2
10 34 a. m.	Do.	77.6
10 48 a. m.	Walking began; 67 meters.	
11 05 a. m.	Walking	72.8
11 10 a. m.	Do.	75.0
11 15 a. m.	Do.	76.5
Mar. 18:		
10^{h}20^{m} a. m.	Standing	84.2
10 24 a. m.	Do.	83.4
10 29 a. m.	Do.	85.6
10 51 a. m.	Walking began; 63 meters.	
10 53 a. m.	Walking (prelim.)	72.4
10 58 a. m.	Do.	73.6
E. D. B.		
Dec. 6.:		
8^{h}56^{m} a. m.	Standing (prelim.)	66.7
8 58 a. m.	Walking began; 45 meters.	
9 23 a. m.	Walking	61.6
9 33 a. m.	Do.	64.4
Jan. 31:		
10^{h}04^{m} a. m.	Standing	83.7
10 08 a. m.	Do.	89.7
10 13 a. m.	Do.	90.2
10 22 a. m.	Walking began; 62 meters.	
10 28 a. m.	Walking (prelim.)	87.5
Feb. 1:		
9^{h}39^{m} a. m.	Standing	93.3
9 45 a. m.	Do.	92.8
9 48 a. m.	Do.	93.3
10 00 a. m.	Walking began; 63 meters.	
10 03 a. m.	Walking (prelim.)	93.4
Mar. 22:		
11^{h}15^{m} a. m.	Standing	72.5
11 29 a. m.	Do.	84.0
11 30 a. m.	Walking began; 75 meters.	
11 33 a. m.	Walking	76.5
11 37 a. m.	Do.	83.8
Mar. 29:		
10^{h}50^{m} a. m.	Standing	80.7
10 53 a. m.	Do.	80.7
E. D. B. (Cont.)		
Mar. 29 (Cont.)		
10^{h}56^{m} a. m.	Standing	86.3
11 10 a. m.	Walking began; 58 meters.	
11 40 a. m.	Walking	83.6
11 49 a. m.	Do.	87.7
Mar. 30:		
10^{h}51^{m} a. m.	Standing	78.2
11 01 a. m.	Do.	87.3
11 10 a. m.	Walking began; 69 meters.	
11 56 a. m.	Walking	83.4
12 01 p. m.	Do.	82.6
Mar. 31:		
10^{h}51^{m} a. m.	Standing	80.7
10 56 a. m.	Do.	77.4
11 01 a. m.	Do.	74.6
11 34 a. m.	Walking began; 55 meters.	
11 55 a. m.	Walking	65.8
12 00 p. m.	Do.	67.3
12 04 p. m.	Do.	70.7
Apr. 1:		
10^{h}34^{m} a. m.	Standing	72.4
10 39 a. m.	Do.	83.6
10 43 a. m.	Do.	81.0
11 04 a. m.	Walking began; 53 meters.	
11 22 a. m.	Walking	71.3
Apr. 3:		
10^{h}31^{m} a. m.	Standing	71.8
10 35 a. m.	Do.	79.2
10 40 a. m.	Do.	78.4
10 56 a. m.	Walking began; 35 meters.	
11 16 a. m.	Walking	63.5
11 22 a. m.	Do.	69.2
11 26 a. m.	Do.	72.7
Apr. 4:		
10^{h}43^{m} a. m.	Standing	84.8
10 47 a. m.	Do.	85.6
11 08 a. m.	Walking began; 36 meters.	
11 26 a. m.	Walking	65.4
11 30 a. m.	Do.	71.5
11 34 a. m.	Do.	69.2
Apr. 5:		
10^{h}31^{m} a. m.	Standing	89.9
10 35 a. m.	Do.	89.3
10 40 a. m.	Do.	90.2
10 57 a. m.	Walking began; 77 meters.	
11 13 a. m.	Walking	84.9
11 17 a. m.	Do.	85.0
11 23 a. m.	Do.	90.0

[1] No records for periods II and III.

two periods no record was available. On March 17 the standing rate of 74.8 to 77.6 was followed by a rate of 72.8 after 17 minutes of walking, which rose in 10 minutes to 76.5. A more pronounced change is seen in the records for March 18, in which case the pulse-rate after the subject had walked 7 minutes was 73.6 as compared with a standing rate of 85.6 at the end of the standing period.

With E. D. B. similar cases were found. The records for February 1 have been included in the table to show that while the standing pulse was abnormally high, the pulse in the preliminary period of walking was also high, although no higher than that for standing. The rates of March 29 and 30 show that though the first walking rate was higher than the first standing rate, it was nevertheless lower than the final standing rate, even though the subject had walked 30 and 46 minutes at a speed of 58 and 69 meters per minute, respectively, between the two sets of pulse-records.

It is thus evident that these records confirm the earlier observations of Benedict and Murschhauser. This fall is so pronounced as to justify the statement that a change from standing to walking at moderate speeds, i. e., 35 to 75 meters per minute, is in many instances accompanied by a decrease in pulse-rate, although the metabolism may simultaneously be doubled or more. In many of the records in table 46, a pulse-rate after a considerable period of forced quiescence is compared with that found early in a period of walking. It may be suggested that the change in walking was possibly agreeable to the subject and thus in part account for the apparent anomaly. This does not, however, explain such definite records as, for instance, those for E. D. B. on March 31, when all of the walking-rates were clearly lower than the standing rates. The fact that these lower rates were found after the subject had been walking in some cases from 15 to 20 minutes precludes the suggestion put forth by Benedict, Miles, Roth, and Smith[1] that possibly the low pulse-rates found by Benedict and Murschhauser had been counted during a moment of pulse-reaction from the first stimulus of walking. The fact that the pulse-rates for walking on a level at a moderate speed can be maintained at a lower rate than when the subject is standing is of prime physiological interest and warrants further study.

Relationship of Oxygen Consumption, Pulse-Rate, and Pulmonary Ventilation During Horizontal Walking.

The relationship between the oxygen consumption and the heat-output of the body is so close that the oxygen consumption may, to a certain extent, be taken as a measure of the heat-output. It has also been shown by Boothby[2] that the oxygen consumption and the ventilation are linear functions, and Means and Newburgh[1] have shown that the same is true for the oxygen consumption and ventilation in relation to work.

---

[1] Benedict, Miles, Roth, and Smith, Carnegie Inst. Wash. Pub. No. 280, 1919, p. 451.

[2] Boothby, Am. Journ. Physiol., 1915, **37**, p. 383.

In figure 13 curves have been plotted for E. D. B. for the total heat-output, oxygen consumption, pulmonary ventilation, respiration, and pulse-rate in relation to the horizontal kilogrammeters (h. kg. m.) of work done, using the average values for the 5-meter speed-groups in table 35, page 144. These curves show how closely the heat-output and the oxygen consumption follow each other with the increasing amount of work done. They also show a constant rate of oxygen consumption up to the point of 2,720 h. kg. m. Above this the oxygen increases at a uniform rate with the work done, if we except the high point of 3,840 h. kg. m., which represents the work done for the most part in October when the experiments were begun with this subject, and he was unused to the apparatus. The curve above 4,560 h. kg. m. is somewhat more sharply ascendant than below that point, but there is no marked alteration in the oxygen consumption.

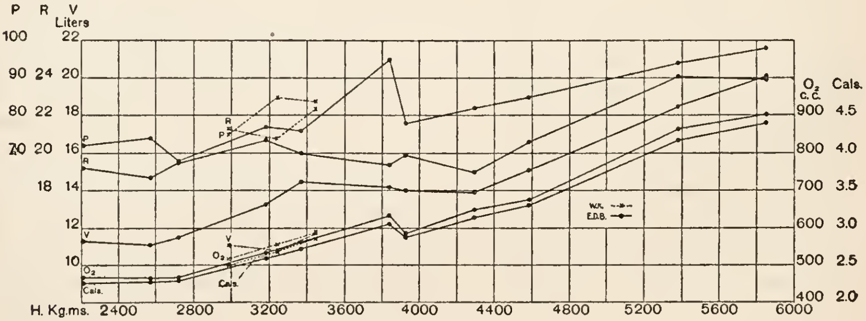

FIG. 13.—Total heat-output (cals.), oxygen consumption (O_2), pulmonary ventilation (V), respiration-rate (R), and pulse-rate (P), of E. D. B. and W. K., referred to horizontal kilogrammeters (h. kg. m.) for experiments with subjects walking on a level at different speeds. (Values per minute.)

The supply of oxygen necessary to meet the increased needs of the body during work is determined by a number of factors, of which pulmonary ventilation and pulse are of special importance. The pulse and ventilation curves should therefore be compared in relation to the oxygen consumption. Like the curve for oxygen, the two curves for pulse-rate and ventilation show no notable changes with the smaller amounts of work. For the larger amounts the increase in the oxygen consumption is followed more closely by the pulse-curve than by the ventilation curve, as the latter does not increase, but remains practically uniform between 3,400 and 4,300 h. kg. m. This would indicate that the necessary oxygen for the increased needs of the body is met by the increase in the pulse-rate and its attendant blood-flow if that factor were known, while a ventilation of 14 liters per minute was sufficient to meet the needs during this range of increasing work. The high oxygen consumption of 633 c. c. at 3,840 h. kg. m. referred to in the previous paragraph is accompanied by an increase in pulse-rate, but no change is evident in the ventilation at this time. Beyond 4,292 h. kg. m. the ventilation curve shows a marked increase, while the increase in the pulse is less in degree, indicating that here the demand for oxygen was not met by an increase in the pulse so much as by a larger pulmonary ventilation. The respiration-rate and the volume per inspiration determine the pulmonary ventilation. A reference to the curve for the respiration-rate shows that up to 4,292 h. kg. m. the increase in the pulmonary ventilation must come from an increase in volume per inspiration rather than from any increase in the respiration-rate. Beyond 4,292 h. kg. m. the respiration-rate shows a sharp increase in keeping with the ventilation. With the data in hand, we are not able to discuss that portion of the compensation due to an increase in the oxygen-carrying power of the blood which is caused by an increase in volume of the heart-output. It is evident, however, that in a change from standing to walking there is possible an actual decrease in pulse-rate with a simultaneous increase of 100 or more per cent in the oxygen consumption. This physiological fact, even though incompletely explained at this time, yet suggests many topics for experimentation.

---

[1] Means and Newburgh, Journ. Pharm. and Exp. Therapeutics, 1915, **7**, p. 449.

The curves for the same factors for W. K. are also given in figure 13, and though the range in the amount of work is much less, the same characteristics are shown by his curves, namely, for the amount of work done, that the oxygen consumption and heat-output run uniformly with the increase in the horizontal kilogrammeters of work, that the ventilation shows no increase for these moderate demands, but that the increase in the pulse-rate is responsible for the increase in the oxygen-supply. The respiration-rate for W. K., in contrast to that of E. D. B., shows an increase with a constant ventilation, indicating a change to a smaller volume per inspiration.

Body-Temperature During Horizontal Walking.

There were 15 days of horizontal walking on which body-temperature measurements were made with E. D. B., including in all 41 experimental periods. These walking experiments were all preceded by standing experiments in which the body-temperature was likewise measured, so that a daily comparison may be made between the standing and horizontal-walking temperatures. These two series of data, which are given in tables 6*a* and 11*a*, pages 53 and 67, are summarized in table 47, in which it is seen that the average temperature during the successive walking-periods increased slightly, even though periods of rest intervened between the periods. It likewise shows that the variations in the average standing temperature were relatively slight from day to day and that the difference between the average standing temperature and the average temperature of the first walking-period shows in several cases a loss. This loss in temperature may have been due to the removal of the blanket from around the subject, with a consequent increase in the loss of heat from the body-surface. (See p. 37.) It may also have been due to a change in position of the thermometer in the rectum, but the care used in inserting the thermometer to a definite depth and the frequent balancing of the leads renders this less likely. It is unfortunate that a blanket had to be used, but it was necessary to protect the subject when he was not exercising.

Table 47.—*Summary of body-temperature measurements of E. D. B. in horizontal-walking experiments without food.*

Date.	Distance walked per minute.	Average body-temperature in successive periods of horizontal-walking experiments.					Average body-temperature during standing.	Increase in body-temperature due to walking.
		First period.	Second period.	Third period.	Fourth period.	Average.		
1916	*meters.*	°*C.*	°*C.*	°*C.*	°*C.*	°*C.*	°*C.*	°*C.*
Apr. 3	35.8	36.86	37.12	37.31	....	37.10	36.68	0.42
4	36.6	36.55	36.73	36.84	....	36.71	36.83	−.12
1	51.8	36.80	37.02	37.17	....	37.00	36.74	.26
Mar. 31	54.1	36.86	37.14	....	....	37.00	36.67	.33
29	56.6	36.91	37.00	....	....	36.96	36.72	.24
20	60.1	36.59	36.78	....	....	36.69	36.60	.09
Jan. 31	63.2	37.03	37.20	37.34	37.42	37.25	37.22	.03
Feb. 1	63.6	37.05	37.21	37.28	37.34	37.22	37.24	−.02
Mar. 30	66.1	37.13	37.17	....	....	37.15	37.07	.08
22	75.9	36.90	37.00	....	....	36.95	36.88	.07
Apr. 5	77.7	37.06	37.23	37.38	....	37.22	36.95	.37
10	77.9	36.95	37.09	....	....	37.02	37.04	−.02
12	88.3	36.95	37.28	37.33	....	37.19	36.95	.04
11	92.3	36.94	37.29	37.43	....	37.22	36.84	.38
13	97.4	37.09	37.46	37.62	....	37.39	36.93	.46
Average...	53.1	36.91	37.18	37.30	37.38	37.07	36.89	.17

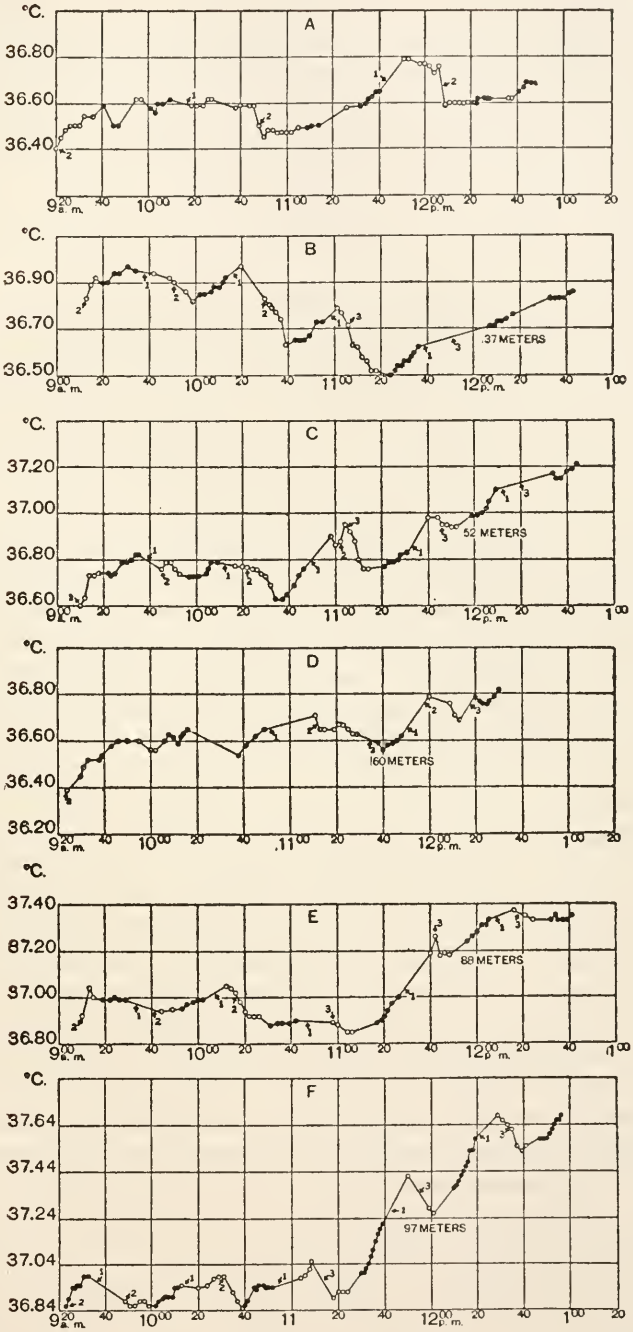

Fig. 14.—Typical body-temperature curves for E. D. B. during periods of standing and periods of walking on a level at various speeds.

1, subject sitting; 2, standing; 3, walking on a level. Readings in experimental periods indicated by black points. Curve A, March 2; B, April 4; C, April 1; D, March 20; E, April 12; F, April 13, 1916.

The relationship between the body-temperature for standing and walking is also shown in figure 14 by 6 typical curves for different speeds of walking. Each temperature reading is indicated, those within the experimental periods being represented by black points and those in the intervals between the experimental periods by small circles. The changes to standing, walking, or sitting are shown by arrows, with accompanying index numbers, and the rate of walking is given in each instance. Curve A, for comparison, records sitting and standing values only.

Nearly every individual period in each curve shows an increase in the temperature during the period with both standing and walking. There is usually a disturbance in the temperature at the points indicated by arrows when the subject changed his position, which is possibly due to a change in position of the thermometer. The curve of April 4 (B) is inserted especially to show the marked variation in temperature which was experienced when the subject stood (2) at $10^h\ 30^m$ a. m. before the third period and again when he began walking (3) at $11^h\ 6^m$ a. m. before the fourth period. It is possible that the depression in temperature before the fourth period may have been due to removal of the blanket, though no note regarding it appears in the records. In both these instances the temperature fell for at least 10 minutes, after which it became settled and subsequently rose as usual. This displacement of the temperature level results in an average walking temperature which is less than the average standing temperature, but it is seen that the increase during the walking-periods was of about the same order as on the other days.

The increase in temperature with the transition from standing to walking does not manifest itself immediately for the moderate speeds (see curves B, C, and D for April 4, April 1, and March 20), there being apparently a lag of from 6 to 10 minutes before the rise appears. This lag is, however, somewhat shortened in curves E and F (April 12 and 13), with speeds of 88 and 97 meters. These latter curves show a much more rapid rise in temperature in each period, with a tendency to reach a maximum, particularly in curve E. The fact that the blanket was removed at the time that the walking began is undoubtedly a factor here in preventing as quick a response as there would have been had the subject stood and walked under exactly the same conditions of clothing. The increase in temperature is almost always larger for the first walking-periods than for the subsequent periods, showing that the difference between the rate of heat-production and radiation was becoming constantly less and that a more or less constant temperature would have been attained had the period been sufficiently prolonged.

The effect of speed of walking upon the temperature curves is not marked, except at the higher rates. The general character of the curves in figure 14 and others not presented indicate but little difference at the different speeds. Apparently the exercise of walking at the normal speeds used for the most part in this research was not sufficient to produce any marked changes in body-temperature. Referring again to table 47, in which it has been necessary to compare only the average temperatures, it is seen that although the highest absolute temperature and largest increases over the standing values are with the highest speeds, the lowest speed also has a high average temperature as well as large increase, and that the increases over the standing temperatures are irregular. The average walking temperature would depend upon the duration of walking as well as upon the speed. Consequently, no definite statement as to the influence of speed can be made other than that, in the intermittent periods here conducted, the maximum increase for any speed below 100 meters per minute did not exceed 0.5° C., and that for moderate speeds the temperature increase would probably be not far from 0.25° C.

Blood-Pressure During Horizontal Walking.

The increase in the supply of oxygen to the tissues with increased demand due to exercise is dependent upon a chain of processes. The increase in pulmonary ventilation and pulse-rate, the change in the distribution of the blood-flow to those muscles more in need of oxygen, and the general increase in the blood-flow itself, all contribute to the immediate supply of oxygen. The increase in the blood-flow is one of the largest, if not the largest, factor in maintaining this addition to the oxygen-supply, and Krogh and Lindhard[1] have shown that during work the blood-flow may be eight times that during rest. This increase in blood-flow is, at least above certain limits, accompanied by an increase in blood-pressure. It thus becomes of interest to record the blood-pressure during periods of exercise, and this was done with E. D. B. for both the standing and walking experiments over a period of several weeks. During this time there were 13 days on which records of the blood-pressure were made for both standing and horizontal-walking periods. These horizontal-walking values are recorded in table 11*a* (p. 67). It should be recalled that they were taken just prior to and immediately following the periods of walking proper, as it was not possible to read the pressure during the act of walking. (See p. 37.) Cotton, Rapport, and Lewis[2] have recently shown that the blood-pressure immediately on the cessation of exercise indicates little or no increase above the resting value, but within 10 seconds it begins to increase and continues to rise for a period of 30 to 60 seconds, after which it again tends to fall to normal value. While it is possible that the readings as reported by us may not have occurred at the point of maximum pressure following walking, it is quite certain that the readings were close to it and beyond the point of minimum value at 10 seconds. Although the readings can not be said to be the blood-pressures *during* horizontal walking, it is believed that they approach closely to them, and as the conditions under which the readings were made were alike, the results are comparable.

---

[1] Krogh and Lindhard, Skand. Arch. f. Physiol., 1912, **27**, p. 100.

[2] Cotton, Rapport, and Lewis, Heart, 1917, **6**, p. 269.

Disregarding the fact that there was some variation in the speed of walking for the periods on the same day, it is seen in table 11*a* that the blood-pressure shows but little tendency to change from period to period on the same day, the difference being ±2 mm., with an extreme of 4 mm. on two occasions.

For a comparison between the average standing and the average walking blood-pressures on the same date, a summary is presented in table 48. The blood-pressure for the first walking-periods is here seen to be 5 to 16 mm. higher than the average standing values for the same day. The average increase is 9 mm.

TABLE 48.—*Summary of blood-pressure records for E. D. B. in horizontal-walking experiments without food.*

Date.	Distance walked per minute.	Average blood-pressure in successive periods of horizontal-walking experiments.				Average blood-pressure during standing.	Increase in blood-pressure due to walking.
		First period.	Second period.	Third period.	Average.		
1916.	*meters.*	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*
Apr. 3	35.8	124	123	121	123	116	7
4	36.6	117	118	118	118	113	5
1	51.8	124	125	123	124	115	9
Mar. 31	54.1	124	127	....	126	120	6
29	56.6	124	125	....	125	109	16
20	60.1	122	123	....	123	114	9
30	66.1	119	117	....	118	113	5
22	75.9	122	118	....	120	110	10
Apr. 5	77.7	123	127	125	125	118	7
10	77.9	129	129	....	129	121	8
12	88.3	130	129	130	130	118	12
11	92.3	130	129	129	129	118	11
13	97.4	131	131	131	131	117	14
Average	67.0	125	125	125	125	116	9

The degree of increase over the standing does not show an evident connection with the speed, nor does the speed of walking show a uniform effect upon the absolute blood-pressure readings until the rate of 88.3 meters per minute is reached. At this point the blood-pressure is noticeably higher than for the more moderate speeds. The average blood-pressure for the horizontal-walking experiments on the days when the speed was 75.9 meters per minute or below was 122 mm., and ranged from 118 to 126 mm. Above 75.9 meters per minute it was 129 mm., ranging from 125 to 131 mm.

The effect of horizontal walking upon the blood-pressure is therefore not large, even at the highest speeds here reported, as compared with the increases in blood-pressures known to occur with other forms of work, such as those found in exercise with dumb-bells by Cotton, Rapport, and Lewis.[1] There is, however, a point above 80 meters per minute at which the effect upon the blood-pressure of the speed of walking may be clearly noted.

EXPERIMENTS WITH GRADE WALKING.

As explained in the section on methods (p. 29), the treadmill was constructed with two long screw members attached to the head, by means of which the front of the treadmill could be raised so as to give angles of elevation as desired up to approximately 45°. Aside from the fact that under these conditions the subject walked on a predetermined incline, the details of the grade-walking experiments were in no respect different from those with horizontal walking. As the degree of elevation increased, less power was needed to drive the treadmill, and at the highest grades the weight of the subject alone would have been sufficient to cause the speed to increase continuously. To control this and thus secure uniformity in speed, an adjustable brake was placed on the shaft of the motor. (See p. 29 and fig. 1, p. 19.) This tendency to an increase in speed during the experiment was a frequent source of trouble, and careful attention was required to prevent any gradual alteration in speed from unexpectedly developing.

The results of the measurements in the grade-walking experiments are given in detail in tables 13 to 16*a* (pp. 69 to 89), in which the values are chronologically arranged for all of the experimental periods with every subject. Before discussing the results of these experiments, a consideration of the method used for studying the respiratory exchange is desirable, more especially the use of the mouthpiece under the special conditions of grade walking.

Physiology of Mouth-Breathing Appliances.

While the mouthpiece in its various forms has been extensively used for respiration experiments with the subject lying or standing or walking, there has been much criticism by investigators as to the physiological effects of using such an appliance. Some go so far as to state that it is physiologically impossible for a man to breathe normally through a mouthpiece. This extreme opinion is held by only a few workers on the respiratory exchange. With walking experiments, however, the question might fairly be raised whether the use of the mouthpiece would affect the results obtained, more especially during the severe exercise of grade walking, when the oxygen consumption would necessarily be very considerable and the pulmonary ventilation especially large. Is the resistance, for example, too great? Of special interest is the fact that much of this report deals with the physiology of respiration during the period of transition from standing to walking, and the reverse from walking to standing. If breathing through a mouthpiece is abnormal, the value of these studies of transition would be lessened.

---

[1] Cotton, Rapport, and Lewis, Heart, 1917, **6**, p. 269.

In the ordinary technique the mouthpiece is usually inserted about two minutes before the actual experiment begins. To test the question as to whether this preliminary period of breathing through the mouthpiece was sufficiently long for the subject to adjust himself to the new conditions, a number of experiments were carried out in which the mouthpiece was inserted 15 or more minutes before the actual beginning of the experiment, and a comparison series of experiments was made in which the mouthpiece was inserted almost immediately, i. e., a few seconds before the period began. These experiments were all with E. D. B. between March 2 and 8, 1916, inclusive. On two of the days the subject stood; on four of the days he walked on a 30 per cent incline at a rate of approximately 50 meters per minute. The standing or walking was continuous on every day throughout each set of two comparison periods, and at the end the subject sat down and rested. In the first period in each pair the subject breathed through the mouthpiece on an average of 15 minutes before the period began. The actual period for the measurement of the metabolism varied from 7 minutes and 24 seconds to 10 minutes and 52 seconds, averaging not far from 9 minutes. There was then an interval which was usually 10 to 12 minutes long. On March 4 the first interval was 20 minutes and on March 7 the interval, owing to some trouble with the apparatus, was 50 minutes. On both these days walking experiments were made, and the subject walked continuously even in these intervals.

In the second period in the comparison the mouthpiece was not inserted until just before the beginning of the test, so that usually the period began on the second respiration, with an interval between the insertion of the mouthpiece and the beginning of the metabolism measurements of never more than 15 seconds. Since this procedure was carried out in both the standing and walking comparisons, it would seem as if the influence of mouthpiece breathing upon the metabolism and physiological factors should be demonstrated by such a series of tests.

Effect of Mouthpiece Breathing upon Metabolism.

Although the data for these comparison tests are incorporated in the statistical tables 6 and 16, they are also summarized here in table 49. In the first test, namely, March 2, 1916, the influence on the metabolism of the time of insertion of the mouthpiece was studied only with the subject standing, and three comparisons were made. On March 3 the

TABLE 49.—*Respiratory exchange of E. D. B. in experiments without food for studying effect of long and short duration of preliminary mouthpiece breathing.*[1] (*Values per minute.*)

Date, No. of comparison, and conditions of experiment.	Work due to grade-lift.[2]		Carbon dioxide.		Oxygen.		Respiratory quotient.	
	After 15 *minutes* preliminary mouthpiece breathing.	After 15 *seconds* preliminary mouthpiece breathing.	After 15 *minutes* preliminary mouthpiece breathing.	After 15 *seconds* preliminary mouthpiece breathing.	After 15 *minutes* preliminary mouthpiece breathing.	After 15 *seconds* preliminary mouthpiece breathing.	After 15 *minutes* preliminary mouthpiece breathing.	After 15 *seconds* preliminary mouthpiece breathing.
Standing.								
Mar. 2:	*kg. m.*	*kg. m.*	*c. c.*	*c. c.*	*c. c.*	*c. c.*		
First			202	192	236	239	0.86	0.81
Second			198	187	244	229	.81	.82
Third			185	192	(3)	(243)	(3)	.79
Average			195	190	240	234	.83	.81
Mar. 3:								
First			186	194	240	244	.78	.80
Second			197	191	241	246	.82	.78
Third			185	186	233	241	.79	.77
Average			189	190	238	243	.80	.79
Grade walking.[4]								
Mar. 4:								
First	898.5	889.4	1,621	1,624	1,764	1,829	.92	.89
Second	863.8	898.5	1,552	1,625	1,751	1,914	.89	.85
Average	881.2	894.0	1,587	1,625	1,758	1,872	.91	.87
Mar. 6:								
First	933.6	953.7	1,763	1,783	1,923	2,013	.92	.89
Second	959.2	968.3	1,800	1,795	2,044	2,015	.88	.89
Average	946.4	961.0	1,782	1,789	1,984	2,014	.90	.89
Mar. 7:								
First	925.7	927.5	1,774	1,682	1,909	1,942	.93	.87
Mar. 8:								
First	924.7	924.7	1,761	1,735	1,891	1,942	.93	.89
Second	926.5	944.5	1,807	1,766	1,961	2,073	.92	.85
Third	930.1	933.7	1,769	1,723	2,011	2,043	.88	.84
Average	927.1	934.3	1,779	1,741	1,954	2,019	.91	.86

---

[1] The subject stood continuously or walked continuously in each comparison, i. e., also in the interval between the two tests. Between the comparisons he sat down and rested for approximately 30 to 40 minutes. The time given for the preliminary mouthpiece breathing is approximate.

[2] See table 55, column *f*, p. 209.

[3] Measurement of oxygen could not be obtained in this period.

[4] In the grade-walking experiments, the grade was 30 p. ct. and the speed averaged 49 meters on March 4, 51 meters on March 6, and 52 meters on March 7 and 8.

series was duplicated under the same conditions. Considering average values only, it can be seen that the carbon dioxide on the first day was slightly larger when the mouthpiece was inserted 15 minutes before the test, but on the second day it was practically the same with both periods of preliminary breathing. The oxygen consumption was somewhat higher on the first day and correspondingly lower on the second day with the long preliminary breathing. The respiratory quotient was slightly higher in both series of tests with the longer preliminary breathing. The evidence as a whole can not be said, however, to indicate that with this subject standing there is an appreciable difference in the effect upon the measured metabolism as to whether the mouthpiece is inserted 15 minutes before the period begins or immediately before.

On four days walking experiments were made, and while there was every effort to secure exactly the same rate of walking, unfortunately this could not be maintained. Slight differences in the total amount of work performed accordingly appear. While the rate of walking was approximately 50 meters per minute, a little less than 2 miles an hour, it actually varied in the different periods on these days from 47.2 to 53.0 meters per minute. Usually the rate of walking was slightly greater with the second test in the comparison, namely, that with the short preliminary breathing, the difference averaging not far from 1 per cent. These differences are important to take into consideration in the analysis of the results.

Of the two factors, carbon dioxide and oxygen, one would naturally expect that an abnormality in respiration due to the mouthpiece would produce more immediate fluctuations in the amount of carbon dioxide exhaled. This may be owing to a local "pumping-out" effect, and consequently it is not surprising that the values for carbon dioxide do not show regularity. On the first two days with grade walking these values are somewhat higher, and on the last two days measurably lower with the short preliminary breathing period. Since, as stated above, when there was a difference in the rate of walking, it was almost invariably more rapid in the second test of the comparison, it can be seen that there is no relationship between the carbon dioxide and the slightly higher rate of walking, nor indeed any relationship with the use of the mouthpiece, and the differences in amounts simply illustrate the variability in the carbon-dioxide excretion that one may expect to find under the conditions of a test like this.

A truer measure of the metabolism is the oxygen consumption, and we find here that on all four days the oxygen consumption was slightly higher in the period with the short preliminary breathing. This is almost always in full accord with the slight differences in the rate of walking, and can therefore be readily explained by an increase in the oxygen consumption necessitated by an increase in the rate of walking.

That it is not wholly explained by this is shown by the fact that the average increase in the rate of walking with the short preliminary breathing period is only about 1 per cent as compared with the actual increment of 2 per cent in the oxygen consumption. The evidence is therefore to the effect that with but 15 seconds of preliminary mouthpiece breathing, a slightly greater oxygen consumption is required during the experimental period than with 15 minutes of preliminary breathing through the mouthpiece.

The respiratory quotient on the four days is invariably lower with the short period of preliminary breathing. At times the difference is very considerable, even as large as 0.06. It is therefore clear that the mouthpiece breathing is not ideally adapted for an analysis of the character of the combustion when heavy work is being performed. A large number of experiments have been made in the Nutrition Laboratory on the comparison of various types of respiration apparatus, using mouthpieces, nosepieces, and masks, and these show that for periods of *rest* no appreciable difference exists between the various types employed.[1] The true respiratory quotient obtained in these walking experiments is difficult to valuate. *A priori*, one could take the ground that the longer the mouthpiece was inserted in the mouth, the more normal the respiration would be. But in any event the percentage error is small, probably not over 2 per cent, and the measurements of the metabolism under conditions of great physical activity, such as obtained in many of the experiments reported in this book, can hardly be much, if any, inside of this limit of accuracy. The natural conclusion is, therefore, that although practically all of the experiments were made with a short period of preliminary mouthpiece breathing, rather than a 15-minute period of preliminary breathing, and these tests indicate that the metabolism is thereby slightly increased if measured by the oxygen consumption, yet it does not seem advisable to attempt a correction of the results for the small differences shown in this series of tests.

As previously stated, in actual experiments the mouthpiece is usually inserted about 2 minutes before the observations of the metabolism begin. This preliminary period is measurably greater than the short period in the series of comparison tests, but much shorter than the 15-minute periods. Doubtless the error due to the insertion of the mouthpiece is not distributed in a straight line, and it is more than reasonable to suppose that at the end of 2 minutes the oxygen consumption is more nearly in accord with that obtained with the longer period of preliminary respiration than with that with the very short period.

---

[1] Carpenter, Carnegie Inst. Wash. Pub. No. 216, 1915. Also, Hendry, Carpenter, and Emmes, Boston Med. and Surg. Journ., 1919, **181**, pp. 285, 334, and 368.

EFFECT OF MOUTHPIECE BREATHING UPON RESPIRATION-RATE, PULMONARY VENTILATION, AND RATE OF OXYGEN CONSUMPTION.

The effect upon the respiration-rate and the pulmonary ventilation of long-continued preliminary breathing through the mouthpiece was also studied in these experiments, for it was conceivable that the mouthpiece and nose-clip might cause a change in the ventilation which would result in a pumping-out of carbon dioxide and a consequent change in the respiratory quotient and the computed heat. As previously stated, in ordinary experimenting it has been the practice to insert the mouthpiece 2 or more minutes before the beginning of the period. If there were any alteration in the respiration-rate and volume of ventilation under these conditions, it ought to be apparent in experiments made with such wide variations in the length of preliminary breathing as comparison periods of 15 seconds and 15 minutes would give. If this variation in conditions resulted in no material difference, it is safe to say that the usual 2-minute period of preliminary breathing through the mouthpiece was sufficient to insure uniformity.

The respiration-rate and pulmonary ventilation were determined in 1-minute and ¼-minute intervals during the first 5 to 7 minutes of the period by counting the respirations and measuring their excursion on the kymograph, the time-intervals being marked in minutes by means of a signal magnet in contact with a clock. The ventilation as thus measured is the apparent ventilation, and the data have not been corrected for temperature changes.

At the time that these measurements of the ventilation were made, advantage was taken of the opportunity to measure the rate of the oxygen consumption during the first few minutes of the period. This was done by the use of the double spirometer (see fig. 2, p. 22), and the measurement of the kymograph record. During the regular experiments it was the practice to admit the oxygen at such a rate as to equalize the consumption, but in determining the rate in the mouthpiece comparison experiments, no oxygen was admitted until the spirometer-bell had reached a low level. The main spirometer was then refilled from the duplicate spirometer by the method described on page 21. Under these conditions, instead of a gradual alteration in the relative positions of the kymograph tracings as a result of the contractions in the volume of the ventilating circuit, the kymograph record showed a slight rise with each respiration and a sudden fall when new oxygen was finally admitted from the duplicate spirometer. By measuring the rise in the kymograph record due to the fall of the spirometer-bell in a specified period of time, the rate of oxygen consumption could be estimated for succeeding fractions of a minute.

There is a valid criticism against this method of measurement, for it assumes that the subject exhales to the same point of deflation of the lungs each time and that the residual volume in the lungs and the temperature conditions remain constant. Any alteration in the residual volume would alter the base of the respiration tracings on the kymograph. This, of course, does occur occasionally in a deep inhalation, but the low points of the tracings which mark the limits of expiration are remarkably uniform after the first few respirations of the period, and the rate at which these points rise give a very fair index of the rate of oxygen consumption. The method, however, is intended merely as an approximate comparison, for the volumes thus read are apparent volumes and, like those for the pulmonary ventilation, are uncorrected for temperature changes.

The lower record (A) in figure 15 is the reproduction of a kymograph tracing when the subject was standing and shows the rise in the curve as the oxygen was absorbed from the ventilating circuit, without renewal. The upper record (B) in the same figure was obtained with the subject walking, and indicates the points at which the main spirometer was refilled from the duplicate spirometer.

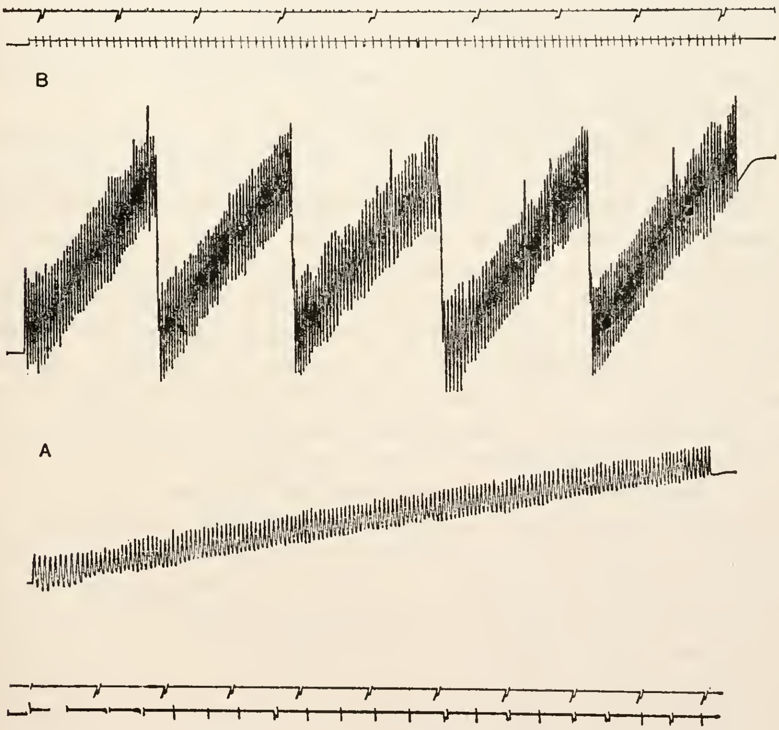

Fig. 15.—Reproduction of kymograph records in mouthpiece experiments, with intermittent renewal of oxygen.

A, subject standing without introduction of oxygen. *B*, subject walking on a 30 per cent grade, 50 meters per minute; intermittent renewal of oxygen. Time and pulmonary ventilation indicated by the horizontal tracings.

EFFECT WITH SUBJECT STANDING.

In table 50 the data for the respiration and ventilation rates obtained with the subject standing are given for E. D. B. for March 2 and 3, 1916. In the first test in each comparison the subject had been standing with the mouthpiece inserted for at least 15 minutes previous to the beginning of the measurements. In this test the values were measured in minute intervals. In the second test of each comparison the mouthpiece was inserted but a few seconds before the measurements began. The measurements were made in quarter minutes and the per minute rate calculated from the results. These quarter-minute rates are also averaged for comparison with the measurement for the corresponding full minute in the preceding test, when the mouthpiece was inserted 15 minutes.

Three comparisons were obtained with the subject standing on both March 2 and 3, with intervals of rest of 30 minutes or more between the first and second and the second and third comparisons. The respiration-rate in the periods when the mouthpiece had been used for approximately 15 minutes does not, on the whole, appear to be different from the rate when the mouthpiece was inserted immediately before the experiment. There seems to be a slight tendency for the respiration-rate to increase with the time, but this is as apparent with the long preliminary breathing as with the short.

In most cases, when the pulmonary ventilation was calculated on the quarter-minute basis, a slightly larger ventilation was found for the first quarter-minute during the periods when the mouthpiece had been but briefly inserted. There are, however, several exceptions to this. No greater variation was found under one condition than under the other, if we take the per minute averages for comparison. With the exception of a slight disturbance for the first one-quarter minute, it appears that the ventilation was as constant under one condition as under the other, and that both the respiration and ventilation with the subject standing were unaffected by the presence of the mouthpiece during a short or a long preliminary breathing.

The oxygen consumption per minute for the first 7 or 8 minutes of each period was computed as outlined on page 182. Considerable variations actually occur in single minutes, the range being, with the subject standing, from 186 to 418 c. c. per minute. Little, if any, regularity can be observed on any day, although it is worthy of note that both the extreme values occurred in the first minute. The inherent errors in the method of measurement outlined above make its use questionable when such small per minute amounts of oxygen were obtained, and hence we do not tabulate them.

EFFECT DURING GRADE WALKING.

On March 4, 6, 7, and 8, the usual grade-walking experiments were varied to the extent that in each alternate period the subject breathed

TABLE 50.—*Respiration-rate and rate of pulmonary ventilation (unreduced) in experiments without food, for studying effect of long and short duration of preliminary mouthpiece breathing. Subject, E. D. B., standing. (Values per minute.)*

Date and interval measured.	First comparison.				Second comparison.				Third comparison.			
	After 15 *minutes* preliminary mouthpiece breathing.		After 15 *seconds* preliminary mouthpiece breathing.		After 15 *minutes* preliminary mouthpiece breathing.		After 15 *seconds* preliminary mouthpiece breathing.		After 15 *minutes* preliminary mouthpiece breathing.		After 15 *seconds* preliminary mouthpiece breathing.	
	Respiration-rate (full minutes).	Rate of pulmonary ventilation unreduced (full minutes).	Respiration-rate (¼ min.).	Rate of pulmonary ventilation, unreduced (¼ min.).	Respiration-rate (full minutes).	Rate of pulmonary ventilation unreduced (full minutes).	Respiration-rate (¼ min.).	Rate of pulmonary ventilation, unreduced (¼ min.).	Respiration-rate (full minutes).	Rate of pulmonary ventilation unreduced (full minutes).	Respiration-rate (¼ min.).	Rate of pulmonary ventilation, unreduced (¼ min.).
1916.		*liters.*		*liters.*		*liters.*		*liters.*		*liters.*		*liters.*
Mar. 2:			15.2	11.2			12.9	9.2			16.6	11.6
			14.3	10.2			13.1	9.3			15.5	11.1
			15.0	10.3			12.9	9.0			15.2	9.6
			15.5	9.0			16.2	8.5			15.2	10.5
1st min.....	15.1	9.5	15.0	10.2	15.9	10.6	13.8	9.0	16.0	9.6	15.6	10.7
			16.6	9.3			15.1	8.0			15.7	9.9
			16.0	10.1			16.3	9.8			15.2	9.9
			16.7	11.2			15.5	11.1			15.7	9.9
			14.5	8.9			16.6	10.6			16.3	9.6
2d min.....	14.6	9.9	16.0	9.9	13.8	9.3	15.9	9.9	15.0	9.6	15.7	9.8
			15.1	9.8			15.2	10.9			15.2	9.8
			16.7	10.6			15.1	10.0			14.0	9.7
			16.1	10.0			15.1	10.1			15.7	10.8
			16.1	9.8			16.0	10.8			15.7	11.2
3d min.....	15.5	10.3	16.0	10.1	13.9	9.0	15.4	10.5	15.7	10.4	15.2	10.4
			16.5	10.6			16.5	10.3			15.7	9.8
			17.2	11.3			15.5	9.5			15.6	9.9
			19.4	13.1			15.1	8.8			16.1	11.4
			17.0	11.0			16.6	10.5			15.1	10.8
4th min.....	15.2	10.4	17.5	11.5	16.3	10.6	15.9	9.8	16.5	10.2	15.6	10.4
			16.5	10.8			16.5	11.6			14.6	9.6
			15.5	11.0			16.5	10.5			14.7	9.3
			16.6	11.6			16.5	10.5			17.4	11.1
			16.2	9.4			17.0	10.0			15.8	11.1
5th min....	16.8	11.1	16.2	10.7	15.1	10.1	16.6	10.6	16.6	10.6	15.6	10.3
			16.2	9.3			....	....			15.8	10.4
6th min....	16.5	10.6	16.6	10.8	....	....	....	....	....	....	16.9	10.7

ABLE 50.—*Respiration-rate and rate of pulmonary ventilation (unreduced) in experiments without food, for studying effect of long and short duration of preliminary mouthpiece breathing. Subject, E. D. B., standing. (Values per minute.)*—Continued.

Date and interval measured.	First comparison.				Second comparison.				Third comparison.			
	After 15 *minutes* preliminary mouthpiece breathing.		After 15 *seconds* preliminary mouthpiece breathing.		After 15 *minutes* preliminary mouthpiece breathing.		After 15 *seconds* preliminary mouthpiece breathing.		After 15 *minutes* preliminary mouthpiece breathing.		After 15 *seconds* preliminary mouthpiece breathing.	
	Respiration-rate (full minutes).	Rate of pulmonary ventilation unreduced (full minutes).	Respiration-rate (¼ min.).	Rate of pulmonary ventilation, unreduced (¼ min.).	Respiration-rate (full minutes).	Rate of pulmonary ventilation unreduced (full minutes).	Respiration-rate (¼ min.).	Rate of pulmonary ventilation, unreduced (¼ min.).	Respiration-rate (full minutes).	Rate of pulmonary ventilation unreduced (full minutes).	Respiration-rate (¼ min.).	Rate of pulmonary ventilation, unreduced (¼ min.).
1916.		*liters.*		*liters.*		*liters.*		*liters.*		*liters.*		*liters.*
Mar. 3:			15.7	11.1			15.0	11.3			13.9	9.8
			15.3	10.4			15.5	9.0			14.1	8.7
			14.8	9.8			15.9	9.8			16.1	10.4
			14.9	10.2			14.4	9.4			15.2	9.9
1st min.....	[1]14.2	9.4	15.2	10.4	15.4	10.7	15.2	9.9	15.6	10.0	14.8	9.7
			14.3	9.3			13.7	8.1			15.7	9.6
			14.2	8.2			15.0	8.8			16.2	10.2
			16.1	10.4			16.6	10.7			15.8	9.7
			16.1	10.7			16.0	10.5			16.2	10.3
2d min.....	[1]14.2	9.4	15.2	9.6	14.5	9.7	15.3	9.5	15.3	9.7	16.0	9.9
			16.1	10.6			15.4	9.9			16.2	10.3
			15.7	9.3			15.5	9.8			16.6	10.7
			15.9	11.1			15.8	9.8			15.7	10.4
			17.0	11.6			14.2	8.5			15.7	10.0
3d min.....	15.3	9.5	16.2	10.6	16.0	10.6	15.2	9.5	16.1	10.6	16.1	10.4
			17.0	11.0			15.8	10.4			15.7	10.2
			16.0	10.0			16.7	11.3			15.8	9.5
			16.5	10.2			17.8	11.9			16.7	10.1
			17.0	10.8			18.1	11.6			15.2	10.0
4th min....	14.2	9.1	16.6	10.5	17.4	11.1	17.1	11.3	16.3	10.5	15.9	9.9
			16.7	11.0			18.2	11.9			16.2	10.1
			14.0	9.9			16.7	11.3			16.9	11.6
			15.7	9.8			15.8	10.7			16.6	11.6
			16.7	11.5			16.6	10.9			16.6	11.0
5th min....	15.1	9.9	15.8	10.6	17.1	11.1	16.8	11.2	16.7	10.7	16.6	11.1
			16.7	12.2			17.6	11.3			15.7	10.1
			16.7	11.5			16.6	10.7			....	....
6th min....	16.7	10.7	16.9	11.5	17.2	11.0	16.8	10.2	....	....	....	....

---

[1] Average of the first two full minutes.

through the mouthpiece for approximately 15 minutes before the period began and from 10 to 15 seconds for the other periods, the procedure being similar to that in the standing tests. In these experiments the oxygen consumption was large and hence the respiration-rate and pulmonary ventilation were correspondingly large. The error in the technique would consequently play a much smaller rôle than in the standing experiments. Table 51 gives the respiration and ventilation rates on these days measured in minute or quarter-minute intervals for the first 5 to 7 minutes of the period.[1] The method of presentation of results is the same as in table 50.

The results show that the respiration-rate underwent no pronounced change in one direction or the other in those periods in which the subject had been breathing through the mouthpiece for 15 minutes and in which the measurements were made on the per minute basis. There was a slight tendency for the rate to be usually a little lower than with the short preliminary use of the mouthpiece. In the quarter-minute measurements there was more variation, which was sufficiently small to be ascribable to the error in estimation for such short periods as one-quarter minute, and this variation was not so uniform as to indicate that the mouthpiece had more than a temporary effect. It would appear, therefore, that the practice in our experiments of inserting the mouthpiece 2 minutes before the period began probably gave ample time for the respiration-rate to become settled, even under conditions requiring a great increase in the rate of respiration.

The pulmonary ventilation in the grade-walking experiments varied considerably from minute to minute. The volumes per minute were usually larger in those periods in which the mouthpiece had just been inserted than in the periods in which it had been used for 15 minutes or more, but this difference tends to become smaller as the experiment progressed. It may also be noted that the ventilation for these periods was frequently larger in the first and second quarter-minutes than in the next following, indicating a rather rapid adjustment to the disturbance of the mouthpiece at the beginning of the period.

From the data in table 51, which usually represent only 5 or 6 minutes of an 8 to 11 minute period, the general impression is obtained that in the majority of periods the unreduced pulmonary ventilation was somewhat higher in those tests with a short period of preliminary mouthpiece breathing. This impression is confirmed by the average values of the *reduced* ventilation for the whole of each period given in table 16 (p. 78) for the several dates. Bearing in mind that the comparison periods were alternate, and that the first measurement on each day was preceded by a long period of mouthpiece breathing, it is seen that the pulmonary ventilation was in all but two sets of comparisons (that of March 7 and the last pair of March 8) *larger* in the period with the short preliminary mouthpiece breathing. Averaging

---

[1] The quarter-minute records were computed to the full-minute basis.

TABLE 51.—*Respiration-rate and rate of pulmonary ventilation (unreduced) in grade-walking experiments without food, for studying effect of long and short duration of preliminary mouthpiece breathing. Subject, E. D. B., 30 per cent grade, at approximately 50 meters. (Values per minute.)*

Date, and interval measured.	First comparison.				Second comparison.				Third comparison.			
	After 15 *minutes* preliminary mouthpiece breathing.		After 15 *seconds* preliminary mouthpiece breathing.		After 15 *minutes* preliminary mouthpiece breathing.		After 15 *seconds* preliminary mouthpiece breathing.		After 15 *minutes* preliminary mouthpiece breathing.		After 15 *seconds* preliminary mouthpiece breathing.	
	Respiration-rate (full minutes).	Rate of pulmonary ventilation unreduced (full minutes).	Respiration-rate (¼ min.).	Rate of pulmonary ventilation, unreduced (¼ min.).	Respiration-rate (full minutes).	Rate of pulmonary ventilation unreduced (full minutes).	Respiration-rate (¼ min.).	Rate of pulmonary ventilation, unreduced (¼ min.).	Respiration-rate (full minutes).	Rate of pulmonary ventilation unreduced (full minutes).	Respiration-rate (¼ min.).	Rate of pulmonary ventilation, unreduced (¼ min.).
1916.		*liters.*		*liters.*		*liters.*				*liters.*		*liters.*
Mar. 4........			27.8	51.7			26.7	52.1			....	....
			27.6	47.4			28.0	50.3			....	....
			29.8	46.2			26.7	46.4			....	....
			28.8	52.6			27.3	47.5			....	....
1st min.....	27.0	47.0	28.5	49.5	29.0	45.0	27.2	49.1	....	....	....	....
			31.4	55.1			29.5	49.5			....	....
			30.3	44.7			28.4	50.7			....	....
			28.8	48.8			32.0	52.6			....	....
			31.7	53.5			26.0	47.0			....	....
2d min.....	28.0	47.9	30.6	50.5	29.3	47.1	29.0	50.0	....	....	....	....
			32.2	53.2			27.3	52.3			....	....
			30.0	49.6			28.0	49.5			....	....
			31.0	54.2			28.0	50.3			....	....
			32.0	57.4			25.8	49.8			....	....
3d min.....	27.5	49.4	31.3	53.6	30.0	48.4	27.3	50.5	....	....	....	....
			30.3	52.6			30.6	49.5			....	....
			36.3	52.4			28.0	45.7			....	....
			32.8	48.3			28.0	51.1			....	....
			30.8	47.0			24.0	44.9			....	....
4th min....	29.0	48.8	32.6	50.1	30.2	49.2	27.7	47.8	....	....	....	....
5th min....	27.4	48.5	29.9	50.8	29.8	49.0	22.1	37.5			....	....
6th min.....	....	....	....	....	30.0	48.9	....	....	....	....	....	....
Mar. 6:			28.5	57.1			28.6	56.2			....	....
			30.0	56.2			31.3	55.6			....	....
			29.5	54.1			30.7	54.2			....	....
			29.7	54.8			31.3	56.1			....	....
1st min.....	29.3	50.5	29.4	55.6	29.0	50.0	30.5	55.5	....	....	....	....

TABLE 51.—*Respiration-rate and rate of pulmonary ventilation (unreduced) in grade-walking experiments without food, for studying effect of long and short duration of preliminary mouthpiece breathing. Subject, E. D. B., 30 per cent grade, at approximately 50 meters. (Values per minute.)*—Continued.

Date and interval measured.	First comparison.				Second comparison.				Third comparison.			
	After 15 *minutes* preliminary mouthpiece breathing.		After 15 *seconds* preliminary mouthpiece breathing.		After 15 *minutes* preliminary mouthpiece breathing.		After 15 *seconds* preliminary mouthpiece breathing.		After 15 *minutes* preliminary mouthpiece breathing.		After 15 *seconds* preliminary mouthpiece breathing.	
	Respiration-rate (full minutes).	Rate of pulmonary ventilation unreduced (full minutes).	Respiration-rate (¼ min.).	Rate of pulmonary ventilation, unreduced (¼ min.).	Respiration-rate (full minutes).	Rate of pulmonary ventilation unreduced (full minutes).	Respiration-rate (¼ min.).	Rate of pulmonary ventilation, unreduced (¼ min.).	Respiration-rate (full minutes).	Rate of pulmonary ventilation unreduced (full minutes).	Respiration-rate (¼ min.).	Rate of pulmonary ventilation, unreduced (¼ min.).
1916.		*liters.*		*liters.*		*liters.*				*liters.*		*liters.*
Mar. 6 (cont.)			29.7	53.2			31.3	53.9			....	....
			28.4	48.8			32.0	54.1			....	....
			31.4	54.1			31.3	53.0			....	....
			29.0	41.6			28.0	51.8			....	....
2d min.....	27.1	50.1	29.6	49.4	28.4	52.3	30.7	53.2	....	....	....	....
			28.6	53.9			30.0	55.3			....	....
			28.0	53.0			30.7	54.6			....	....
			27.3	49.5			32.5	55.0			....	....
			28.8	50.3			32.0	56.8			....	....
3d min......	28.2	49.6	28.2	51.7	27.3	52.4	31.3	55.4	....	....	....	....
			29.8	51.5			34.5	57.9			....	....
			31.8	56.7			29.9	50.5			....	....
			32.0	55.6			30.8	55.7			....	....
			30.3	49.1			31.6	53.9			....	....
4th min.....	27.1	50.0	31.0	53.2	27.2	51.1	31.7	54.5	....	....	....	....
			30.1	53.6			33.6	55.1			....	....
			31.0	55.4			33.6	60.7			....	....
5th min....	26.6	51.1	31.1	55.1	28.4	53.8	32.2	61.4	....	....	....	....
Mar. 7:												
			22.8	51.5			....	....			....	....
			26.7	49.3			....	....			....	....
			31.2	50.4			....	....			....	....
			26.6	49.5			....	....			....	....
1st min.....	26.0	45.5	26.8	50.2	....	....	....	....	....	....	....	....
			26.2	43.8			....	....			....	....
			27.7	49.0			....	....			....	....
			29.1	49.4			....	....			....	....
			29.4	47.4			....	....			....	....
2d min.....	29.5	49.1	28.1	47.4	....	....	....	....	....	....	....	....

TABLE 51.—*Respiration-rate and rate of pulmonary ventilation (unreduced) in grade-walking experiments without food, for studying effect of long and short duration of preliminary mouthpiece breathing. Subject, E. D. B., 30 per cent grade, at approximately 50 meters. (Values per minute.)*—Continued.

Date and interval measured.	First comparison.				Second comparison.				Third comparison.			
	After 15 *minutes* preliminary mouthpiece breathing.		After 15 *seconds* preliminary mouthpiece breathing.		After 15 *minutes* preliminary mouthpiece breathing.		After 15 *seconds* preliminary mouthpiece breathing.		After 15 *minutes* preliminary mouthpiece breathing.		After 15 *seconds* preliminary mouthpiec breathing.	
	Respiration-rate (full minutes).	Rate of pulmonary ventilation unreduced (full minutes).	Respiration-rate (¼ min.).	Rate of pulmonary ventilation, unreduced (¼ min.).	Respiration-rate (full minutes).	Rate of pulmonary ventilation unreduced (full minutes).	Respiration-rate (¼ min.).	Rate of pulmonary ventilation, unreduced (¼ min.).	Respiration-rate (full minutes).	Rate of pulmonary ventilation unreduced (full minutes).	Respiration-rate (¼ min.).	Rate of pulmonary ventilation, unreduced (¼ min.).
1916.		*liters.*		*liters.*		*liters.*		*liters.*		*liters.*		*liters.*
Mar. 7 (cont.)			28.2	54.5			......	......			......	......
			30.2	48.9			......	......			......	......
			28.7	48.8			......	......			......	......
			29.2	51.7			......	......			......	......
3d min.....	28.3	47.7	29.1	51.0	......	......	......	......	......	......	......	......
			25.8	51.3			......	......			......	......
			28.9	49.3			......	......			......	......
			27.5	51.0			......	......			......	......
			30.5	52.3			......	......			......	......
4th min....	28.0	49.8	28.2	51.0	......	......	......	......	......	......	......	......
			29.1	50.2			......	......			......	......
			30.2	52.6			......	......			......	......
			24.6	53.2			......	......			......	......
			26.8	48.1			......	......			......	......
5th min.....	29.6	54.3	27.7	51.0	......	......	......	......	......	......	......	......
6th min....	28.8	52.5	......	......			......	......			......	......
7th min.....	28.1	49.4	......	......			......	......			......	......
Mar. 8:												
			21.8	42.2			28.9	53.3			28.9	57.2
			21.8	43.8			26.8	50.2			29.1	53.6
			25.9	46.7			28.5	49.1			30.2	50.5
			27.3	51.3			28.5	52.2			32.4	55.2
1st min....	25.5	48.9	24.2	46.0	29.5	52.1	28.2	51.2	29.7	53.0	30.2	54.1
			29.4	51.2			32.6	59.8			32.5	59.4
			30.7	58.7			34.1	60.8			31.8	63.4
			28.7	55.8			32.6	66.7			27.7	59.4
			28.4	52.5			29.8	57.1			29.6	56.5
2d min......	28.6	54.5	29.3	54.6	30.8	59.4	32.3	61.1	28.0	58.1	30.4	59.7

TABLE 51.—*Respiration-rate and rate of pulmonary ventilation (unreduced) in grade-walking experiments without food, for studying effect of long and short duration of preliminary mouthpiece breathing. Subject, E. D. B., 30 per cent grade, at approximately 50 meters. (Values per minute.)*—Continued.

Date and interval measured.	First comparison.				Second comparison.				Third comparison.			
	After 15 *minutes* preliminary mouthpiece breathing.		After 15 *seconds* preliminary mouthpiece breathing.		After 15 *minutes* preliminary mouthpiece breathing.		After 15 *seconds* preliminary mouthpiece breathing.		After 15 *minutes* preliminary mouthpiece breathing.		After 15 *seconds* preliminary mouthpiece breathing.	
	Respiration-rate (full minutes).	Rate of pulmonary ventilation unreduced (full minutes).	Respiration-rate (¼ min.).	Rate of pulmonary ventilation, unreduced (¼ min.).	Respiration-rate (full minutes).	Rate of pulmonary ventilation unreduced (full minutes).	Respiration-rate (¼ min.).	Rate of pulmonary ventilation, unreduced (¼ min.).	Respiration-rate (full minutes).	Rate of pulmonary ventilation unreduced (full minutes).	Respiration-rate (¼ min.).	Rate of pulmonary ventilation, unreduced (¼ min.)
1916.		*liters.*		*liters.*		*liters.*		*liters.*		*liters.*		*liters.*
Mar. 8 (cont.)			33.5	59.1			33.2	57.4			26.9	51.3
			33.5	50.9			31.6	50.7			27.5	52.3
			31.8	53.2			34.4	61.6			30.3	53.9
			30.3	54.0			30.0	57.2			31.8	57.0
3d min.....	29.5	53.6	32.3	54.3	31.4	54.6	32.3	56.7	30.5	55.1	29.1	53.6
			32.2	60.1			31.1	63.1			30.8	60.5
			28.7	61.2			26.8	58.2			29.2	59.4
			30.4	48.8			27.8	50.2			30.7	52.6
			30.7	51.9			34.2	55.4			29.9	49.7
4th min.....	29.5	57.1	30.5	55.5	29.5	61.4	30.0	56.7	29.5	59.6	30.2	55.6
			31.3	55.7			34.2	59.7			29.4	50.8
			28.7	54.0			38.5	71.3			30.9	55.0
			32.4	60.6			34.4	66.7			30.4	57.9
			32.7	60.5			27.1	65.6			27.7	58.9
5th min.....	29.1	56.6	31.3	57.7	30.0	55.0	33.6	65.8	29.9	56.4	29.6	55.7
6th min.....	....	....	....	....			30.2	54.9			....	....

all of the periods for each method of test on these 4 days, we find the average *reduced* ventilation for the periods with long preliminary mouthpiece breathing to be 45.8 liters and that for the periods with short preliminary breathing to be 46.7 liters, with a difference of 0.9 liter or 1.97 per cent. (See table 16, p. 78).

At first sight this relatively small difference appears to be a real effect, ascribable to the short use of the mouthpiece. It is important to bear in mind, however, that, as previously pointed out, the actual amount of work performed in the two series was usually somewhat greater in the second set of tests, this difference being not far from 1 per cent. Allowing for this disparity in amount of work, the apparent difference between the series of tests is reduced to about 1 per cent, which may well be stated to be within the limits of experimental error and not sufficiently pronounced to indicate a real physiological difference in the two methods of preliminary breathing.

Owing to the fact that a slightly larger amount of work was usually performed in the second test of each comparison set, i. e., when the experiment was preceded by but 15 seconds of breathing through the mouthpiece, the slightly larger oxygen consumption noted in these periods (see tables 16 and 49) may be explained without attributing it to the type of respiration preceding the experiment. In the hope that a study of the rate of oxygen consumption from minute to minute might throw some light upon the effect of mouthpiece breathing, such computations from the kymograph curves during grade-walking tests were made. The results which are not tabulated, showed no decided change in the oxygen consumption nor any marked alteration in the rate of absorption at the beginning of the period. The variations are, in a number of cases, very large and are probably due to errors in the estimation of the time from the slope of the curve—errors which are fundamental to the method. The evidence of both the total per minute values in tables 16 and 49, and the values calculated from the kymograph curves, suggests no appreciable difference in the rate of oxygen consumption in the two series of tests which is not substantially accounted for by the small difference in the amount of work done.

CONCLUSIONS WITH REGARD TO THE EFFECT OF LONG AND SHORT PRELIMINARY MOUTHPIECE BREATHING.

A close study of the respiration-rate, pulmonary ventilation, and oxygen consumption shows no appreciable differences between the two types of preliminary breathing other than what can reasonably be ascribed to the unfortunate but unavoidable slight differences in the amount of work done. On the other hand, it is quite clear that the respiratory quotient is materially affected by the type of respiration, particularly in the walking experiments, being almost invariably much lower with the short preliminary mouthpiece breathing.

One would normally assume that with the long preliminary breathing there would have been a period of adjustment, so that with the beginning of the metabolism measurements the amount of carbon dioxide exhaled would be essentially that produced. Immediately after the insertion of the mouthpiece, particularly if there is any adjustment of the respiration to the new conditions, as there usually is, one can expect either an excessive removal of carbon dioxide due to pumping-out or possibly the storage of carbon dioxide due to a reduced ventilation. The former is usually the case, and it can be easily seen that the amount of carbon dioxide exhaled would then be larger than that actually produced; consequently, when metabolism measurements are made after a very brief period of mouthpiece breathing, the respiratory quotient would be large. As a matter of fact, under exactly these conditions of experimenting, we find a quotient somewhat smaller than those obtained during the tests with a long preliminary period of mouthpiece breathing. No simple explanation for this is at hand.

These tests have, however, considerable significance in that they indicate the necessity of caution in employing short-period respiration experiments for the computation of the total energy production, especially if the collection of expired air is begun immediately after the mouthpiece is inserted. This is all the more important, since there is an increasing tendency on the part of certain physiologists to utilize the carbon-dioxide exhalation alone as a measure of the metabolism.[1]

When carbon dioxide only is measured during periods of muscular repose, there is nothing in our results to throw any discredit upon the actual determination of carbon dioxide. Indeed, if the respiratory quotient is determined, it seems to be essentially the same, irrespective of the type of respiration. On the other hand, in experiments in which heavy work is performed, and particularly when the mouthpiece is used, and the whole computation of energy is based upon carbon dioxide alone, it is easy to err in selecting the respiratory quotient to be used. To be sure, in many of these tests only an approximate computation of energy is desired. It is important, however, to bear in mind that in this series of comparison tests there is grave doubt of the accuracy of the determination of the respiratory quotient when the period of measurement is preceded by a very short period of preliminary breathing through the mouthpiece.

METABOLISM OF SUBJECTS WALKING ON AN INCLINE.

In addition to the chronological presentation of the data obtained in the grade-walking experiments in tables 13 to 16, the metabolism measurements have also been assembled in tables 52 to 55, to show the effect of the work performed in the grade walking upon the heat-output in excess of both the standing and the horizontal-walking requirements. These tables show the work performed and the increase in the heat-output. The effect of grade and speed upon the heat-output, the physiological factors, and the efficiency is brought out by a summary of the data in table 56.

In considering the effect of grade walking upon the energy output as presented in tables 52 to 55, it has been assumed that the basal requirements of the body at rest, i. e., standing, did not alter during the walk-

---

[1] Benedict, Miles, Roth, and Smith, Carnegie Inst. Wash. Pub. No. 280, 1919, p. 119, table 5, footnote 2; Benedict and Johnson, Proc. Am. Phil. Soc., 1919, **58**, p. 89; Benedict, Collins, Hendry, and Johnson, N. H. College of Agr., Tech. Bull. No. 16, 1920; Waller, Proc. Physiol. Soc., 1918–19, **52**, pp. xlviii, l, lix, lxvii, and lxxii; 1919, **53**, pp. xxiv, xxx, and xliv.

TABLE 52.—*Increase in the heat-output of A. J. O. and H. R. R. during grade walking in experiments without food. (Values per minute.)*

Subject and date.	(*a*) Body-weight with clothing.	(*b*) Grade.	(*c*) Distance walked.	(*d*) Horizontal component of distance.	(*e*) Grade-lift of body. ($b \times c$)	(*f*) Work due to grade-lift. ($e \times a$)	(*g*) Step-lift.	(*h*) Work due to step-lift. ($g \times a$)	(*i*) Work of total lift (work of ascent). ($f+h$)
A. J. O.	*kg.*	*p. ct.*	*meters.*	*meters.*	*meters.*	*kg. m.*	*meters.*	*kg. m.*	*kg. m.*
Mar. 2	....	....	61.1	61.1	2.20	162.8	....	....	....
	....	....	68.1	68.1	2.45	181.3	....	....	....
Average	74.0	3.6	64.6	64.6	2.33	172.1	....	....	....
H. R. R.									
Mar. 27	....	....	66.4	66.0	7.04	516.0	1.18	86.5	602.5
	....	....	66.4	66.0	7.04	516.0	1.68	123.1	639.1
	....	....	66.8	66.4	7.08	519.0	1.90	139.3	658.3
	....	....	66.6	66.2	7.06	517.5	2.26	165.7	683.2
Average	73.3	10.6	66.6	66.2	7.06	517.1	1.76	128.7	645.8
Apr. 3	....	....	61.7	61.4	6.29	451.0	1.23	88.2	539.2
	....	....	61.9	61.6	6.31	452.4	1.31	93.9	546.3
	....	....	61.8	61.5	6.30	451.7	1.29	92.5	544.2
	....	....	62.2	61.9	6.34	454.6	1.36	97.5	552.1
Average	71.7	10.2	61.9	61.6	6.31	452.4	1.30	93.0	545.5
Apr. 24	....	....	63.8	63.4	6.70	473.0	1.56	110.1	583.1
	....	....	64.2	63.8	6.74	475.8	1.68	118.6	594.4
	....	....	64.1	63.7	6.73	475.1	1.76	124.3	599.4
Average	70.6	10.5	64.0	63.6	6.72	474.6	1.67	117.7	592.3
May 1	....	....	71.8	71.4	7.54	542.9	2.02	145.4	688.3
	....	....	72.5	72.1	7.61	547.9	2.15	154.8	702.7
	....	....	73.1	72.7	7.68	553.0	2.47	177.8	730.8
	....	....	73.2	72.8	7.69	553.7	2.71	195.1	748.8
	....	....	73.0	72.6	7.67	552.2	3.07	221.0	773.2
	....	....	72.9	72.5	7.65	550.8	3.27	235.4	786.2
Average	72.0	10.5	72.8	72.4	7.64	550.1	2.62	188.3	738.3
May 8	....	....	75.9	75.5	7.97	575.4	2.44	176.2	751.6
	....	....	76.1	75.7	7.99	576.9	2.86	206.5	783.4
	....	....	76.5	76.1	8.03	579.8	2.95	213.0	792.8
	....	....	76.7	76.3	8.05	581.2	3.26	235.4	816.6
	....	....	77.0	76.6	8.09	584.1	3.22	232.5	816.6
	....	....	77.0	76.6	8.09	584.1	3.47	250.5	834.6
Average	72.2	10.5	76.5	76.1	8.04	580.3	3.03	219.0	799.3
May 22	....	....	66.5	65.7	10.17	720.0	1.94	137.4	857.4
	....	....	66.3	65.5	10.14	717.9	1.99	140.9	858.8
	....	....	65.7	64.9	10.05	711.5	2.11	149.4	860.9
	....	....	66.3	65.5	10.14	717.9	2.49	176.3	894.2
Average	70.8	15.3	66.2	65.4	10.13	716.8	2.13	151.0	867.8

TABLE 52.—*Increase in the heat-output of A. J. O. and H. R. R. during grade walking in experiments without food. (Values per minute.)*—Continued.

Subject and date.	(*j*) Total heat during grade walking (computed).	(*k*) Heat due to standing.[1]	(*l*) Increment over standing requirement. (*j*−*k*)	Heat due to horizontal component.		Increment in heat over standing and horizontal component due to grade-lift.		(*q*) Efficiency for grade-lift. $\frac{2.34\times100}{p}$
				(*m*) Per h. kg. m.	(*n*) Total. $\frac{d\times a\times m}{1000}$	(*o*) Total. (*l*−*n*)	(*p*) Per kg. m. of grade-lift. $\frac{o\times1000}{f}$	
A. J. O.	*cals.*	*cals.*	*cals.*	*gm.-cal.*	*cals.*	*cals.*	*gm.-cals.*	*p. ct.*
Mar. 2..........	4.25	....	2.94	....	2.04	0.90	5.5	42.5
	4.66	....	3.35	....	2.28	1.07	5.9	39.7
Average....	4.45	1.31	3.14	[2]0.452	2.16	.98	5.6	41.8
H. R. R.								
Mar. 27.........	8.17	....	6.83	....	2.95	3.88	7.5	31.2
	8.16	....	6.82	....	2.95	3.87	7.5	31.2
	8.35	....	7.01	....	2.97	4.04	7.8	30.0
	8.40	....	7.06	....	2.94	4.10	7.9	29.5
Average....	8.26	1.34	6.92	[2].610	2.96	3.96	7.7	30.4
Apr. 3.........	7.47	....	6.13	....	2.79	3.34	7.4	31.6
	7.53	....	6.19	....	2.80	3.39	7.5	31.2
	7.61	....	6.27	....	2.80	3.47	7.7	30.4
	7.88	....	6.54	....	2.81	3.73	8.2	28.5
Average....	7.62	1.34	6.28	[2].634	2.80	3.48	7.7	30.4
Apr. 24.........	7.28	....	5.94	....	2.56	3.38	7.1	33.0
	7.46	....	6.12	....	2.58	3.54	7.4	31.6
	7.37	....	6.03	....	2.58	3.45	7.3	32.0
Average....	7.36	1.34	6.02	[2].574	2.57	3.45	7.3	32.0
May 1	8.17	....	6.83	....	3.18	3.65	6.7	34.9
	8.31	....	6.97	....	3.21	3.76	6.9	33.9
	8.49	....	7.15	....	3.23	3.92	7.1	33.0
	8.90	....	7.56	....	3.24	4.32	7.8	30.0
	8.92	....	7.58	....	3.23	4.35	7.9	29.6
	8.81	....	7.47	....	3.23	4.24	7.7	30.4
Average....	8.59	1.34	7.25	[3].618	3.22	4.03	7.3	32.1
May 8.........	8.54	....	7.20	....	3.37	3.83	6.7	34.9
	8.68	....	7.34	....	3.38	3.96	6.9	33.9
	8.87	....	7.53	....	3.40	4.13	7.1	33.0
	9.04	....	7.70	....	3.40	4.30	7.4	31.6
	9.20	....	7.86	....	3.42	4.44	7.6	30.8
	9.28	....	7.94	....	3.42	4.52	7.7	30.4
Average....	8.93	1.34	7.59	[3].618	3.40	4.19	7.2	32.5
May 22.........	9.89	....	8.55	....	2.87	5.68	7.9	29.6
	9.89	....	8.55	....	2.87	5.68	7.9	29.6
	9.93	....	8.59	....	2.84	5.75	8.1	28.9
	10.13	....	8.79	....	2.87	5.92	8.2	28.5
Average....	9.95	1.34	8.61	[3].618	2.86	5.75	8.0	29.3

[1] General averages for these subjects. See last column of table 3, p. 43.
[2] Average for day. See column *i* of table 29, p. 120.
[3] General average used, as no horizontal walking was done on these days.

TABLE 53.—*Increase in the heat-output of T. H. H. during grade walking in experiments without food. (Values per minute.)*

Subject and date.	(a) Body-weight with clothing.	(b) Grade.	(c) Distance walked.	(d) Horizontal component of distance.	(e) Grade-lift of body. (b×c)	(f) Work due to grade-lift. (e×a)	(g) Step-lift.	(h) Work due to step-lift. (g×a)	(i) Work of total lift (work of ascent). (f+h)
	kg.	p. ct.	meters.	meters.	meters.	kg. m.	meters.	kg. m.	kg. m.
Mar. 24			63.4	63.1	6.53	367.0	2.49	139.9	506.9
			62.3	62.0	6.42	360.8	2.48	139.4	500.2
			62.1	61.8	6.40	359.7	2.46	138.3	498.0
Average	56.2	10.3	62.6	62.3	6.45	362.5	2.48	139.2	501.7
Mar. 26			63.4	63.1	6.53	366.3	2.80	157.1	523.4
			64.3	64.0	6.62	371.4	2.69	150.9	522.3
			64.1	63.8	6.60	370.3	2.77	155.4	525.7
			63.9	63.6	6.58	369.1	2.62	147.0	516.1
Average	56.1	10.3	63.9	63.6	6.58	369.3	2.72	152.6	521.9
Mar. 30			62.1	61.8	6.33	355.7	2.45	137.7	493.4
			61.0	60.7	6.22	349.6	2.40	134.9	484.5
			61.3	61.0	6.25	351.3	2.48	139.4	489.7
Average	56.2	10.2	61.5	61.2	6.27	352.2	2.44	137.3	489.2
Apr. 5			62.3	62.0	6.48	367.4	2.48	140.6	508.0
			63.2	62.9	6.57	372.5	2.51	142.3	514.8
			63.7	63.4	6.62	375.4	2.68	152.0	527.4
Average	56.7	10.4	63.1	62.8	6.56	371.8	2.56	145.0	516.7
Apr. 6			58.4	58.1	6.07	338.1	2.30	128.1	466.2
			59.3	59.0	6.17	343.7	2.44	135.9	479.6
			60.2	59.9	6.26	348.7	2.50	139.3	488.0
			59.4	59.1	6.18	344.2	2.53	141.0	485.2
			60.1	59.7	6.25	348.1	2.56	142.6	490.7
			60.4	60.1	6.28	349.8	2.62	145.9	495.7
Average	55.7	10.4	59.6	59.3	6.20	345.4	2.49	138.8	484.2
Apr. 7			56.1	55.8	5.83	324.7	2.34	130.3	455.0
			56.4	56.1	5.87	327.0	2.24	124.8	451.8
			56.3	56.0	5.86	326.4	2.34	130.3	456.7
			56.6	56.3	5.89	328.1	2.42	134.8	462.9
			56.5	56.2	5.88	327.5	2.46	137.0	464.5
			57.2	56.9	5.95	331.4	2.46	137.0	468.4
			57.6	57.3	5.99	333.6	2.46	137.0	470.6
Average	55.7	10.4	56.7	56.4	5.90	328.4	2.39	133.0	461.6
Apr. 8			67.8	67.4	7.05	389.9	2.83	156.5	546.4
			68.0	67.6	7.07	391.0	2.84	157.1	548.1
			67.5	67.1	7.02	388.2	2.94	162.6	550.8
			67.9	67.5	7.06	390.4	3.23	178.6	569.0
			68.6	68.2	7.13	394.3	3.31	183.0	577.3
			69.0	68.6	7.18	397.1	3.29	181.9	579.0
Average	55.3	10.4	68.1	67.7	7.09	391.8	3.07	170.0	562.4
Apr. 15			63.9	63.6	6.58	374.4	2.79	158.8	533.2
			65.0	64.6	6.70	381.2	2.89	164.4	545.6
			64.8	64.5	6.64	377.8	2.80	159.3	537.1
			65.0	64.7	6.66	379.0	2.90	165.0	544.0
			65.4	65.1	6.71	381.8	2.94	167.3	549.1
			65.9	65.6	6.76	384.6	2.96	168.4	553.0
Average	56.9	10.3	65.0	64.7	6.68	379.8	2.88	163.9	543.7

Table 53.—*Increase in the heat-output of T. H. H. during grade walking in experiments without food. (Values per minute)*—Continued.

Subject and date.	(*j*) Total heat during grade walking (computed).	(*k*) Heat due to standing.	(*l*) Increment over standing requirement. (*j*−*k*)	Heat due to horizontal component.		Increment in heat over standing and horizontal component due to grade-lift.		(*q*) Efficiency for grade-lift. $\frac{2.34\times 100}{p}$
				(*m*) Per h. kg. m.	(*n*) Total. $\frac{d\times a\times m}{1000}$	(*o*) Total. (*l*−*n*)	(*p*) Per kg.m. of grade-lift. $\frac{o\times 1000}{f}$	
	cals.	*cals.*	*cals.*	*gm.-cal.*	*cals.*	*cals.*	*gm.-cals.*	*p. ct.*
Mar. 24	5.61	....	4.50	....	1.99	2.51	6.8	34.4
	5.73	....	4.62	....	1.96	2.66	7.3	32.1
	5.61	....	4.50	....	1.95	2.55	7.1	33.0
Average	5.64	[1]1.11	4.53	[2]0.562	1.97	2.56	7.1	33.0
Mar. 26	5.79	....	4.68	....	1.98	2.70	7.4	31.6
	5.87	....	4.76	....	2.01	2.75	7.5	31.2
	5.97	....	4.86	....	2.00	2.86	7.7	30.4
	6.07	....	4.96	....	1.99	2.97	8.1	28.9
Average	5.93	[1]1.11	4.82	[2].559	1.99	2.83	7.7	30.4
Mar. 30	5.80	....	4.69	....	2.10	2.59	7.3	32.1
	5.70	....	4.59	....	2.07	2.52	7.2	32.5
	5.91	....	4.80	....	2.08	2.72	7.7	30.4
Average	5.80	[1]1.11	4.69	[2].606	2.08	2.61	7.4	31.6
Apr. 5	6.03	....	4.92	....	2.24	2.68	7.3	32.1
	6.28	....	5.17	....	2.27	2.90	7.8	30.0
	6.40	....	5.29	....	2.29	3.00	8.0	29.3
Average	6.24	[1]1.11	5.13	[2].637	2.27	2.86	7.8	30.0
Apr. 6	5.59	....	4.48	....	1.87	2.61	7.7	30.4
	5.62	....	4.51	....	1.90	2.61	7.6	30.8
	5.70	....	4.59	....	1.93	2.66	7.6	30.8
	6.04	....	4.93	....	1.91	3.92	8.8	26.6
	5.94	....	4.83	....	1.93	2.90	8.3	28.2
	6.11	....	5.00	....	1.94	3.06	8.7	26.8
Average	5.83	[1]1.11	4.72	[3].579	1.91	2.81	8.1	28.9
Apr. 7	5.45	....	4.34	....	1.80	2.54	7.8	30.0
	5.50	....	4.39	....	1.83	2.55	7.8	30.0
	5.47	....	4.36	....	1.81	2.55	7.5	31.2
	5.56	....	4.45	....	1.82	2.63	7.7	30.4
	5.57	....	4.46	....	1.81	2.65	8.1	28.9
	5.79	....	4.68	....	1.84	2.84	8.6	27.2
	5.80	....	4.69	....	1.85	2.84	8.5	27.5
Average	5.59	[1]1.11	4.48	[3].579	1.82	2.66	8.1	28.9
Apr. 8	6.34	....	5.23	....	2.16	3.07	7.9	29.6
	6.23	....	5.12	....	2.16	2.96	7.6	30.8
	6.33	....	5.22	....	2.15	3.07	7.9	29.6
	6.40	....	5.29	....	2.16	3.13	8.0	29.3
	6.48	....	5.37	....	2.18	3.19	8.1	28.9
	6.58	....	5.47	....	2.20	3.27	8.2	28.5
Average	6.39	[1]1.11	5.28	[3].579	2.17	3.11	7.9	29.6
Apr. 15	5.70	....	4.59	....	2.14	2.45	6.6	35.5
	5.84	....	4.73	....	2.13	2.60	6.8	34.4
	5.79	....	4.68	....	2.12	2.56	6.8	34.4
	5.81	....	4.70	....	2.13	2.57	6.8	34.4
	5.91	....	4.80	....	2.14	2.66	7.0	33.4
	5.98	....	4.87	....	2.16	2.71	7.0	33.4
Average	5.84	[1]1.11	4.73	[3].579	2.13	2.60	6.8	34.4

[1] Average of the values obtained in all standing experiments with this subject. (See last column of table 4, p. 44.)

[2] Average value obtained on the day of the experiment. (See column *i*, table 30, p. 122.)

[3] Average of the values obtained in all horizontal-walking experiments with this subject. (See column *i*, table 30, p. 122.)

ing, and that the excess energy expended for the grade walking was the energy required to lift the body to a vertical elevation, this elevation being computed from the grade of the treadmill and the linear distance walked at this grade; also that the energy expended for the horizontal component of this linear distance was the same per meter as that determined in the horizontal-walking experiments. Still another assumption is made, namely, that during grade walking there is a certain amount of step-lift, which constitutes a varying amount of work to be added to the work of grade elevation. An effort was made to measure this step-lift and to compute the work which it represented and the energy which it required. It is necessary to consider, therefore, (1) the work due to the grade of the treadmill, which is referred to as the work of grade-lift; (2) the work due to the heel-and-toe action, i. e., the step-lift; and (3) the sum of these two, which constitutes the work of ascent. As was the case in the horizontal-walking experiments, the measured value of the step-lift is of somewhat doubtful dependability; this in turn affects the total amount of work, the so-called work of ascent. The measure of the work due to grade-lift is, however, believed to be accurate. It will therefore be considered more fully than the other factors, and has been used as the basis of the curves presented in this section.

The method by which the grade-lift was measured and the computation of the horizontal component of the distance walked have been explained on page 29. (See also fig. 6.) With the low grades this latter value, shown in column *d* of tables 52 to 55, differs but little from the total distance walked.

The values used for the standing requirement, which have been deducted from the total energy to find the energy requirement for walking, are generally the average values for a period of days, although the average found for that particular day has been used in many instances. The values employed are, in all cases, indicated by footnotes in the tables. In determining the energy to be deducted for the horizontal component, use has been made of the increment per horizontal kilogrammeter, if found for the day of experiment, and, if not, an average value was employed. When any wide deviation appeared in the values for a subject during the period of study, as was the case with E. D. B., the average value, if employed, is that which in our judgment more nearly represents the average increment at the time of the grade-walking experiments.

TABLE 54.—*Increase in the heat-output of W. K. during grade walking in experiments without food.* (*Values per minute.*)

Subject and date.	(*a*) Body-weight with clothing.	(*b*) Grade.	(*c*) Distance walked.	(*d*) Horizontal component of distance.	(*e*) Grade-lift of body. (*b* × *c*)	(*f*) Work due to grade-lift. (*e* × *a*)	(*g*) Step-lift.	(*h*) Work due to step-lift. (*g* × *a*)	(*i*) Work of total lift (work of ascent). (*f* + *h*)	(*j*) Total heat during grade walking (computed).	(*k*) Heat due to standing.	(*l*) Increment over standing requirement. (*j* — *k*)	Heat due to horizontal component. (*m*) Per horizontal kilogrammeter.	Heat due to horizontal component. (*n*) Total. $\frac{d \times a \times m}{1,000}$	Increment in heat over standing and horizontal components due to grade-lift. (*o*) Total. (*l* — *n*)	Increment in heat over standing and horizontal components due to grade-lift. (*p*) Per kg. m. of grade-lift. $\frac{o \times 1,000}{f}$	(*q*) Efficiency for grade-lift. $\frac{2.34 \times 100}{p}$
	kg.	*p. ct.*	*meters.*	*meters.*	*meters.*	*kg. m.*	*meters.*	*kg. m.*	*kg. m.*	*cals.*	*cals.*	*cals.*	*gm.-cal.*	*cals.*	*cals.*	*gm.-cals.*	*p. ct.*
Mar. 4			69.5	69.5	2.50	131.3	1.41	74.0	205.3	4.00		2.90		2.09	0.81	6.2	37.7
			68.9	68.9	2.48	130.2	1.35	70.9	201.1	3.79		2.69		2.08	.61	4.7	49.8
			68.9	68.9	2.48	130.2	1.46	76.7	206.9	3.85		2.75		2.08	.67	5.1	45.9
Average	52.5	3.6	69.1	69.1	2.49	130.6	1.41	73.9	204.4	3.88	[1]1.10	2.78	[2]0.574	2.08	.70	5.3	44.2
Mar. 5			67.5	67.5	2.43	127.8	1.45	76.3	204.1	3.71		2.61		1.83	.78	6.1	38.4
			68.3	68.3	2.46	129.4	1.54	81.0	210.4	3.71		2.64		1.85	.76	5.9	39.2
			68.3	68.3	2.46	129.4	1.60	84.2	213.6	3.71		2.61		1.85	.76	5.9	39.7
			68.4	68.4	2.46	129.4	1.67	87.8	217.2	3.73		2.63		1.85	.78	6.0	39.0
Average	52.6	3.6	68.1	68.1	2.45	129.0	1.57	82.3	211.3	3.72	[1]1.10	2.62	[2].515	1.84	.78	6.0	39.0
Mar. 8			68.9	68.8	2.69	141.2	1.42	74.6	215.8	3.85		2.75		1.85	.90	6.4	36.6
			69.6	69.5	2.71	142.3	1.40	73.5	215.8	4.06		2.96		1.88	1.08	7.7	30.4
			70.1	70.0	2.73	143.3	1.56	81.9	225.2	3.95		2.85		1.89	.96	6.7	34.9
Average	52.5	3.9	69.5	69.4	2.71	142.3	1.46	76.7	218.9	3.95	[1]1.10	2.85	[2].514	1.87	.98	7.0	33.4
Mar. 9			70.0	69.9	2.73	142.2	.93	48.5	190.7	3.87		2.77		1.76	1.01	7.2	32.5
			70.5	70.4	2.75	143.3	1.10	57.3	200.6	3.86		2.74		1.78	.96	7.0	33.4
Average	52.1	3.9	70.3	70.2	2.74	142.8	1.02	52.9	195.7	3.86	[1]1.10	2.76	[2].484	1.77	.99	7.0	33.4
Mar. 23			63.2	62.9	5.81	293.4	2.05	103.5	396.9	4.91		3.81		1.59	2.22	7.5	31.2
			66.6	66.3	6.13	309.6	1.68	84.8	394.4	4.81		3.71		1.68	2.03	6.5	36.0
			63.2	62.9	5.81	293.4	2.35	118.7	412.1	4.98		3.88		1.59	2.29	7.8	30.0
			63.5	63.2	5.84	294.9	2.39	120.7	415.6	5.06		3.96		1.60	2.36	8.0	29.3
Average	50.5	9.2	64.1	63.8	5.90	297.8	2.12	106.9	404.8	4.97	[1]1.10	3.87	[2].501	1.61	2.26	7.6	30.8

[1] General average of values obtained with subject in all standing experiments. See last column of table 5, p. 44.
[2] Average for the day. See column *i* of table 31, p. 123.

TABLE 54.—*Increase in the heat-output of W. K. during grade walking in experiments without food.* (*Values per minute.*)—Continued.

Subject and date.	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)	Heat due to horizontal component.		Increment in heat over standing and horizontal components due to grade-lift.		(q)
	Body-weight with clothing.	Grade.	Distance walked.	Horizontal component of distance.	Grade-lift of body. (b × c)	Work due to grade-lift. (e × a)	Step-lift.	Work due to step-lift. (g × a)	Work of total lift (work of ascent). (f + h)	Total heat during grade walking (computed).	Heat due to standing.	Increment over standing requirement. (j − k)	(m) Per horizontal kilogrammeter.	(n) Total. $\frac{d \times a \times m}{1,000}$	(o) Total. (l − n)	(p) Per kg. m. of grade-lift. $\frac{o \times 1,000}{f}$	Efficiency for grade-lift. $\frac{2.34 \times 100}{p}$
	kg.	*p. ct.*	*meters.*	*meters.*	*meters.*	*kg. m.*	*meters.*	*kg. m.*	*kg. m.*	*cals.*	*cals.*	*cals.*	*gm.-cal.*	*cals.*	*cals.*	*gm.-cals.*	*p. ct.*
Mar. 25	......	......	60.9	60.6	6.52	329.3	2.43	122.7	452.0	4.99	......	3.89	......	1.56	2.33	7.1	33.0
	......	......	60.8	60.5	6.51	328.8	2.40	121.2	450.0	5.07	......	3.97	......	1.56	2.41	7.3	32.1
	......	......	60.8	60.5	6.51	328.8	2.26	114.1	442.9	5.03	......	3.93	......	1.56	2.37	7.2	32.5
Average	50.5	10.7	60.8	60.5	6.51	329.0	2.36	119.3	448.3	5.02	[1]1.10	3.92	[2]0.511	1.56	2.36	7.2	32.5
Mar. 31	......	......	58.3	58.0	6.00	306.0	2.20	112.2	418.2	4.77	......	3.67	......	1.30	2.37	7.7	30.4
	......	......	58.3	58.0	6.00	306.0	2.23	113.7	419.7	4.81	......	3.77	......	1.30	2.47	8.6	28.9
	......	......	58.2	57.9	5.99	305.5	2.26	115.3	420.8	4.83	......	3.73	......	1.30	2.43	8.0	29.3
	......	......	58.9	58.6	6.07	309.6	2.46	125.5	435.1	4.99	......	3.89	......	1.31	2.58	8.3	28.2
Average	51.0	10.3	58.4	58.1	6.02	306.8	2.29	114.2	423.5	4.85	[1]1.10	3.75	[3].440	1.30	2.45	8.0	29.3
Apr. 2	......	......	57.6	57.3	5.93	302.4	1.27	64.8	367.2	4.74	......	3.64	......	1.43	2.21	7.3	32.1
	......	......	57.9	57.6	5.96	304.0	1.65	84.2	388.2	4.75	......	3.65	......	1.44	2.21	7.2	32.5
	......	......	57.9	57.6	5.96	304.0	1.93	98.4	402.4	5.22	......	4.12	......	1.44	2.68	8.8	26.6
	......	......	58.8	58.5	6.06	309.1	2.12	108.1	417.2	4.82	......	3.72	......	1.46	2.26	7.3	32.1
	......	......	58.7	58.4	6.05	308.6	2.22	113.2	421.8	5.20	......	4.10	......	1.46	2.64	8.5	27.5
	......	......	58.6	58.3	6.04	308.0	2.15	109.7	417.7	4.83	......	3.73	......	1.46	2.27	7.3	32.1
	......	......	57.7	57.4	5.94	302.9	2.09	106.6	409.5	4.80	......	3.70	......	1.44	2.26	7.5	31.2
Average	51.0	10.3	58.2	57.9	5.99	305.6	1.92	97.9	403.4	4.90	[1]1.10	3.80	[3].490	1.45	2.35	7.7	30.4
Apr. 12	......	......	59.5	59.2	6.25	314.4	2.32	116.7	431.1	4.95	......	3.85	......	1.46	2.39	7.5	31.2
	......	......	59.8	59.5	6.28	315.9	2.31	116.2	432.1	5.00	......	3.90	......	1.47	2.43	7.7	30.4
	......	......	59.1	58.8	6.21	312.4	2.38	119.7	432.1	4.86	......	3.76	......	1.45	2.31	7.4	31.6
	......	......	59.1	58.8	6.21	312.4	2.42	121.7	434.1	4.99	......	3.89	......	1.45	2.44	7.8	30.0
	......	......	57.9	57.6	6.08	305.8	2.31	116.2	422.0	4.93	......	3.83	......	1.42	2.41	7.8	30.0
	......	......	58.1	57.8	6.10	306.8	2.36	118.7	425.5	5.15	......	4.05	......	1.43	2.62	8.5	27.5
	......	......	58.0	57.7	6.09	306.3	2.30	115.7	422.0	4.89	......	3.79	......	1.43	2.36	7.7	30.4
Average	50.3	10.5	58.8	58.5	6.17	310.6	2.34	117.8	428.4	4.97	[1]1.10	3.87	[3].490	1.44	2.43	7.8	30.0

Apr. 13	......	......	58.6	58.3	6.15	312.4	2.06	104.6	417.0	5.10	......	4.00	......	1.45	2.55	8.1	28.9
	......	......	58.2	57.9	6.11	310.4	2.05	104.1	414.5	4.75	......	3.65	......	1.44	2.21	7.1	33.0
	......	......	58.3	58.0	6.12	310.9	2.06	104.6	415.5	4.76	......	3.66	......	1.45	2.21	7.1	33.0
Average	50.8	10.5	58.4	58.1	6.13	311.2	2.06	104.4	415.7	4.86	[1]1.10	3.76	[3].490	1.45	2.31	7.4	31.6
Apr. 14	......	......	63.9	63.5	6.71	344.2	2.40	123.1	467.3	5.13	......	4.03	......	1.60	2.43	7.0	33.4
	......	......	64.5	64.1	6.77	347.3	2.52	129.3	476.6	5.21	......	4.11	......	1.61	2.50	7.2	32.5
	......	......	64.5	64.1	6.77	347.3	2.64	135.4	482.7	5.12	......	4.02	......	1.61	2.41	7.0	33.4
	......	......	64.9	64.5	6.81	349.4	2.59	132.9	482.3	5.38	......	4.28	......	1.62	2.66	7.6	30.8
	......	......	65.0	64.6	6.83	350.4	2.56	131.3	481.7	5.20	......	4.10	......	1.63	2.47	7.0	33.4
Average	51.3	10.5	64.6	64.2	6.78	347.7	2.54	130.4	478.1	5.21	[1]1.10	4.11	[3].490	1.62	2.49	7.2	32.5
Apr. 16	......	......	64.1	63.8	6.60	333.3	2.28	115.1	448.4	5.17	......	4.07	......	1.58	2.49	7.5	31.2
	......	......	64.1	63.8	6.60	333.3	2.13	107.6	440.9	4.98	......	3.88	......	1.58	2.30	6.9	33.9
	......	......	64.4	64.1	6.63	334.8	2.35	118.7	453.5	5.46	......	4.36	......	1.59	2.77	8.2	28.5
	......	......	64.1	63.8	6.60	333.3	2.38	120.2	453.5	5.06	......	3.96	......	1.58	2.38	7.1	33.0
	......	......	64.4	64.1	6.63	334.8	2.55	128.8	463.6	5.07	......	3.97	......	1.59	2.38	7.1	33.0
	......	......	64.9	64.6	6.68	337.3	2.63	132.8	470.1	5.17	......	4.07	......	1.60	2.47	7.3	32.1
	......	......	65.2	64.9	6.72	339.4	2.68	135.3	474.7	5.19	......	4.09	......	1.61	2.48	7.3	32.1
Average	50.5	10.3	64.5	64.2	6.64	335.2	2.43	122.6	457.8	5.15	[1]1.10	4.05	[3].490	1.59	2.46	7.3	32.1
Apr. 20	......	......	69.2	68.8	7.27	366.4	2.84	143.1	509.5	5.78	......	4.68	......	1.70	2.98	8.1	28.9
	......	......	69.6	69.2	7.31	368.4	3.05	153.7	522.1	5.81	......	4.71	......	1.71	3.00	8.1	28.9
	......	......	69.1	68.7	7.26	365.9	3.24	163.3	529.2	5.41	......	4.31	......	1.70	2.61	7.1	33.0
	......	......	69.3	68.9	7.28	366.9	3.17	159.8	526.7	5.46	......	4.36	......	1.71	2.65	7.2	32.5
	......	......	69.2	68.8	7.27	366.4	3.13	157.8	524.2	5.38	......	4.28	......	1.70	2.58	7.0	33.4
	......	......	69.7	69.3	7.32	368.9	3.14	158.3	527.2	5.99	......	4.89	......	1.71	3.18	8.6	27.2
Average	50.4	10.5	69.4	69.0	7.29	367.2	3.10	156.0	523.2	5.73	[1]1.10	4.54	[3].490	1.71	2.83	7.7	30.4
Apr. 21	......	......	70.0	69.6	7.35	373.4	2.74	139.2	512.6	5.59	......	4.19	......	1.74	2.75	7.4	31.6
	......	......	70.0	69.6	7.35	373.4	2.89	146.8	520.2	5.83	......	4.73	......	1.74	2.99	8.1	28.9
	......	......	70.1	69.7	7.36	373.9	2.85	144.8	518.7	5.72	......	4.62	......	1.74	2.88	7.7	30.4
	......	......	71.6	71.2	7.52	382.0	3.09	157.0	539.0	5.59	......	4.49	......	1.78	2.71	7.1	33.0
	......	......	72.0	71.6	7.56	384.0	3.12	158.5	542.5	5.60	......	4.50	......	1.79	2.71	7.1	33.0
Average	50.8	10.5	70.7	70.3	7.43	377.3	2.94	149.3	526.6	5.68	[1]1.10	4.58	[3].490	1.75	2.83	7.5	31.2
Apr. 22	......	......	70,7	70,3	7.42	376.9	3,00	152,4	529.3	6.25	......	5.15	......	1.75	3.40	9.1	25.7
	......	......	70.9	70.5	7.44	378.0	3.00	152.4	530.4	5.86	......	4.76	......	1.76	3.00	7.9	29.6
	......	......	72.2	71.8	7.58	385.1	3.09	157.0	542.1	5.97	......	4.87	......	1.79	3.08	8.0	29.3
	......	......	72.0	71.6	7.56	384.0	3.05	154.9	538.9	6.23	......	5.13	......	1.79	3.34	8.7	26.9
	......	......	71.3	70.9	7.49	380.5	3.04	154.4	534.9	5.96	......	4.86	......	1.77	3.09	8.1	28.9
	......	......	71.7	71.3	7.53	382.5	3.12	158.5	541.0	5.96	......	4.86	......	1.78	3.08	8.0	29.3
Average	50.8	10.5	71.5	71.1	7.50	381.2	3.05	154.9	536.1	6.04	[1]1.10	4.94	[3].490	1.77	3.17	8.3	28.3

[1] General average of values obtained with subject in all standing experiments. See last column of table 5, p. 44.
[2] Average for the day. See column *i* of table 31, p. 123.
[3] General average for this subject of increments in the heat per horizontal kilogrammeter in horizontal walking. See column *i*, table 31, p. 123.

TABLE 54.—*Increase in the heat-output of W. K. during grade walking in experiments without food.* (*Values per minute.*)—Continued.

Subject and date.	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)	Heat due to horizontal component.		Increment in heat over standing and horizontal components due to grade-lift.		(q)
	Body-weight with clothing.	Grade.	Distance. walked.	Horizontal component of distance.	Grade-lift of body. (b × c)	Work due to grade-lift. (e × a)	Step-lift.	Work due to step-lift. (g × a)	Work of total lift (work of ascent). (f + h)	Total heat during grade walking (computed).	Heat due to standing.	Increment over standing requirement. (j − k)	(m) Per horizontal kilogrammeter	(n) Total. $\frac{d \times a \times m}{1,000}$	(o) Total. (l − n)	(p) Per kg. m. of grade-lift. $\frac{o \times 1,000}{f}$	Efficiency for grade-lift. $\frac{2.34 \times 100}{p}$
	kg.	*p. ct.*	*meters.*	*meters.*	*meters.*	*kg. m.*	*meters.*	*kg. m.*	*kg. m.*	*cals.*	*cals.*	*cals.*	*gm.-cal.*	*cals.*	*cals.*	*gm.-cals.*	*p. ct.*
Apr. 23	......	......	70.7	70.3	7.42	374.7	2.94	148.5	523.2	5.81	......	4.71	......	1.74	2.97	7.9	29.6
	......	......	71.2	70.8	7.48	377.7	2.88	145.4	523.1	5.68	......	4.58	......	1.76	2.82	7.2	32.5
	......	......	71.4	71.0	7.50	378.7	3.03	153.0	531.7	5.76	......	4.66	......	1.76	2.90	7.6	30.8
	......	......	71.3	70.9	7.49	378.2	3.01	152.0	530.2	6.01	......	4.91	......	1.76	3.15	8.3	28.2
	......	......	71.8	71.4	7.54	380.8	3.23	163.1	543.9	5.98	......	4.88	......	1.77	3.11	8.2	28.5
Average	50.5	10.5	71.3	70.9	7.49	378.0	3.02	152.4	530.4	5.84	[1]1.10	4.74	[2]0.490	1.76	2.98	7.9	29.6
Apr. 26	......	......	74.9	74.5	7.86	397.7	3.40	172.0	569.7	6.03	......	4.93	......	1.85	3.08	7.7	30.4
	......	......	75.5	75.1	7.93	401.3	3.33	168.5	569.8	5.99	......	4.89	......	1.87	3.02	7.5	31.2
	......	......	75.9	75.5	7.97	403.3	3.33	168.5	571.8	6.05	......	4.95	......	1.88	3.07	7.6	30.8
	......	......	76.3	75.9	8.01	405.3	3.31	167.5	572.8	6.15	......	5.05	......	1.89	3.16	7.8	30.0
	......	......	76.6	76.2	8.04	406.8	3.40	172.0	578.8	6.13	......	5.03	......	1.89	3.14	7.7	30.4
	......	......	77.5	77.1	8.14	411.9	3.71	187.7	599.6	6.11	......	5.01	......	1.92	3.09	7.5	31.2
Average	50.6	10.5	76.1	75.7	7.99	404.4	3.41	172.7	577.1	6.07	[1]1.10	4.97	[2].490	1.88	3.09	7.6	30.8
Apr. 27	......	......	76.2	75.8	8.00	408.8	3.20	163.5	572.3	6.19	......	5.09	......	1.90	3.19	7.8	30.0
	......	......	76.9	76.5	8.07	412.4	3.18	162.5	574.9	6.21	......	5.11	......	1.92	3.19	7.7	30.4
	......	......	77.1	76.7	8.10	413.9	3.33	170.2	584.1	6.32	......	5.22	......	1.92	3.30	8.0	29.3
	......	......	76.9	76.5	8.07	412.4	3.27	167.1	579.5	5.95	......	4.85	......	1.92	2.93	7.1	33.0
	......	......	77.4	77.0	8.13	415.4	3.34	170.7	586.1	6.59	......	5.49	......	1.93	3.56	8.6	27.2
	......	......	77.8	77.4	8.17	417.5	3.74	191.1	608.6	6.21	......	5.11	......	1.94	3.17	7.6	30.8
Average	51.1	10.5	77.1	76.7	8.09	413.4	3.34	170.9	584.3	6.23	[1]1.10	5.13	[2].490	1.92	3.21	7.8	30.0
Apr. 28	......	......	75.6	75.2	7.94	404.9	3.43	174.9	579.8	6.70	......	5.60	......	1.88	3.72	9.1	25.7
	......	......	76.1	75.7	7.99	407.5	3.69	188.2	595.7	6.31	......	5.21	......	1.90	3.31	8.1	28.9
	......	......	76.7	76.3	8.05	410.6	3.83	195.3	605.9	6.02	......	4.92	......	1.91	3.01	7.3	32.1
	......	......	77.1	76.7	8.10	413.1	4.19	213.7	626.8	6.08	......	4.98	......	1.92	3.06	7.4	31.6
Average	51.0	10.5	76.4	76.0	8.02	409.0	3.79	193.0	602.1	6.28	[1]1.10	5.18	[2].490	1.90	3.28	8.0	29.3

Apr. 29			75.1	74.7	7.89	402.4	3.57	182.1	584.5	6.06		4.96		1.87	3.09	7.7	30.4
			75.8	75.4	7.96	406.0	3.60	183.6	589.6	5.87		4.77		1.89	2.88	7.1	33.0
			76.0	75.6	7.98	407.0	3.79	193.3	600.3	5.92		4.82		1.89	2.93	7.2	32.5
			76.8	76.4	8.06	411.1	3.79	193.3	604.4	5.95		4.85		1.91	2.94	7.1	33.0
			77.1	76.7	8.10	413.1	4.02	205.0	618.1	6.12		5.02		1.92	3.10	7.5	31.2
			76.9	76.5	8.07	411.6	3.99	203.5	615.1	6.31		5.21		1.92	3.29	8.0	29.3
Average	51.0	10.5	76.3	75.9	8.01	408.5	3.79	193.5	602.0	6.04	[1]1.10	4.94	[2].490	1.90	3.04	7.4	31.6
Apr. 30			77.7	77.3	8.16	415.3	4.32	219.9	635.2	6.08		4.98		1.93	3.05	7.3	32.1
			78.8	78.4	8.27	420.9	4.31	219.4	640.3	6.27		5.17		1.96	3.21	7.6	30.8
			79.9	79.5	8.39	427.1	4.30	218.9	646.0	6.47		5.37		1.99	3.38	7.9	29.6
			80.2	79.8	8.42	428.6	4.57	232.6	661.2	6.50		5.40		1.99	3.41	7.9	29.6
			80.9	80.5	8.49	432.1	4.75	241.8	673.9	6.64		5.54		2.01	3.53	8.2	28.5
			81.3	80.9	8.54	434.7	4.97	253.0	687.7	6.77		5.67		2.02	3.65	8.4	27.8
Average	50.9	10.5	79.8	79.4	8.38	426.4	4.54	230.9	657.4	6.44	[1]1.10	5.36	[2].490	1.98	3.38	7.9	29.6
May 4			77.0	76.6	8.09	413.4	3.65	186.5	599.9	6.21		5.11		1.92	3.19	7.7	30.4
			78.1	77.7	8.20	419.0	3.91	199.8	618.8	6.53		5.43		1.95	3.48	8.3	28.2
			78.4	78.0	8.23	420.6	4.05	207.0	627.6	6.19		5.09		1.96	3.13	7.4	31.6
			78.6	78.2	8.25	421.6	4.18	213.6	635.2	6.19		5.09		1.96	3.13	7.4	31.6
			79.1	78.7	8.31	424.6	4.37	223.3	647.9	6.93		5.83		1.97	3.86	9.1	25.7
			79.3	78.9	8.33	425.7	4.34	221.8	647.5	6.42		5.32		1.98	3.34	7.8	30.0
Average	51.1	10.5	78.4	78.0	8.24	420.8	4.08	208.7	629.5	6.40	[1]1.10	5.30	[2].490	1.96	3.34	7.9	29.6
May 5			77.2	76.8	8.11	414.4	4.11	210.0	624.4	6.03		4.93		1.93	3.00	7.3	32.1
			77.8	77.4	8.17	417.5	4.31	220.2	637.7	6.70		5.60		1.94	3.66	8.7	26.9
			78.3	77.9	8.22	420.0	4.28	218.7	638.7	6.18		5.08		1.95	3.13	7.4	31.6
			78.6	78.2	8.25	421.6	4.47	228.4	650.0	6.28		5.18		1.96	3.22	7.6	30.8
			79.5	79.1	8.35	426.7	4.61	235.6	662.3	6.33		5.23		1.98	3.25	7.6	30.8
			80.1	79.7	8.41	429.8	4.73	241.7	671.5	6.57		5.47		2.00	3.47	8.1	28.9
Average	51.1	10.5	78.6	78.2	8.25	421.7	4.42	225.8	647.4	6.35	[1]1.10	5.25	[2].490	1.96	3.29	7.8	30.0
May 10			53.6	53.0	8.04	410.0	2.58	131.6	541.6	5.66		4.56		1.33	3.23	7.9	29.6
			54.0	53.4	8.10	413.1	2.87	146.4	559.5	5.68		4.58		1.34	3.24	7.9	29.6
			55.0	54.4	8.25	420.8	2.75	140.2	561.0	6.03		4.93		1.36	3.57	8.5	27.5
			55.7	55.1	8.36	426.4	3.03	154.5	580.9	6.12		5.02		1.38	3.64	8.5	27.5
			56.0	55.4	8.40	428.4	3.27	166.8	595.2	6.09		4.99		1.39	3.60	8.4	27.8
Average	51.0	15.0	54.9	54.3	8.23	419.7	2.90	147.9	567.6	5.92	[1]1.10	4.82	[2].490	1.36	3.46	8.2	28.5
May 11			57.5	57.0	7.48	380.0	2.59	131.6	511.6	5.62		4.52		1.42	3.10	8.1	28.9
			56.6	56.1	7.36	373.9	2.48	126.0	499.9	5.14		4.04		1.40	2.64	7.1	33.0
			56.6	56.1	7.36	373.9	2.48	126.0	499.9	5.11		4.01		1.40	2.61	7.0	33.4
			57.9	57.4	7.53	382.5	2.56	130.0	512.5	5.27		4.17		1.43	2.74	7.1	33.0
			58.1	57.6	7.55	383.5	2.58	131.1	514.6	5.60		4.50		1.44	3.06	8.0	29.3
			58.0	57.5	7.54	383.0	2.84	144.3	527.3	5.48		4.38		1.43	2.95	7.7	30.4
Average	50.8	13.0	57.5	57.0	7.47	379.5	2.59	131.5	511.0	5.37	[1]1.10	4.27	[2].490	1.42	2.85	7.5	31.2

[1] General average of values obtained with subject in all standing experiments. See last column of table 5, p. 44.

[2] General average for this subject of increments in the heat per horizontal kilogrammeter in horizontal walking. See column *i*, table 31, p. 123.

TABLE 54.—*Increase in the heat-output of W. K. during grade walking in experiments without food. (Values per minute.)*—Continued.

Subject and date.	(a) Body-weight with clothing.	(b) Grade.	(c) Distance walked.	(d) Horizontal component of distance.	(e) Grade-lift of body. (b × c)	(f) Work due to grade-lift. (e × a)	(g) Step-lift.	(h) Work due to step-lift. (g × a)	(i) Work of total lift (work of ascent). (f + h)	(j) Total heat during grade walking (computed).	(k) Heat due to standing.	(l) Increment over standing requirement. (j − k)	Heat due to horizontal component. (m) Per horizontal kilogram-meter.	Heat due to horizontal component. (n) Total. $\frac{d \times a \times m}{1,000}$	Increment in heat over standing and horizontal components due to grade-lift. (o) Total. (l − n)	Increment in heat over standing and horizontal components due to grade-lift. (p) Per kg. m. of grade-lift. $\frac{o \times 1,000}{f}$	(q) Efficiency for grade-lift. $\frac{2.34 \times 100}{p}$
	kg.	*p. ct.*	*meters.*	*meters.*	*meters.*	*kg. m.*	*meters.*	*kg. m.*	*kg. m.*	*cals.*	*cals.*	*cals.*	*gm.-cal.*	*cals.*	*cals.*	*gm.-cals.*	*p. ct.*
May 12	......	......	58.3	57.8	7.58	382.0	2.65	133.6	515.6	5.62	......	4.52	......	1.43	3.09	8.1	28.9
	......	......	58.4	57.9	7.59	382.5	2.82	142.1	524.6	5.30	......	4.20	......	1.43	2.77	7.2	32.5
	......	......	58.6	58.1	7.62	384.0	2.86	144.1	528.1	5.48	......	4.38	......	1.44	2.94	7.7	30.4
	......	......	59.0	58.5	7.67	386.6	2.82	142.1	528.7	5.39	......	4.29	......	1.45	2.84	7.3	32.1
	......	......	58.9	58.4	7.66	386.1	2.90	146.2	532.3	5.46	......	4.36	......	1.45	2.91	7.5	31.2
	......	......	59.1	58.6	7.68	387.1	2.75	138.6	525.7	5.44	......	4.34	......	1.45	2.89	7.5	31.2
Average	50.4	13.0	58.7	58.2	7.63	384.7	2.80	141.1	525.8	5.45	[1]1.10	4.35	[2]0.490	1.44	2.91	7.5	31.2
May 13	......	......	60.4	59.7	9.06	461.2	3.56	181.2	642.4	6.56	......	5.46	......	1.49	3.97	8.6	27.2
	......	......	60.2	59.5	9.03	459.6	3.67	186.8	646.4	6.71	......	5.61	......	1.49	4.12	9.0	26.0
	......	......	59.8	59.1	8.97	456.6	3.77	191.9	648.5	6.83	......	5.73	......	1.48	4.25	9.3	25.2
	......	......	59.9	59.2	8.99	457.6	3.78	192.4	650.0	6.69	......	5.59	......	1.48	4.11	9.0	26.0
	......	......	59.5	58.8	8.93	454.5	3.86	196.5	651.0	6.31	......	5.21	......	1.47	3.74	8.2	28.5
	......	......	59.2	58.5	8.88	452.0	3.81	193.9	645.9	6.33	......	5.23	......	1.46	3.77	8.3	28.2
Average	50.9	15.0	59.8	59.1	8.98	456.9	3.74	190.5	647.4	6.57	[1]1.10	5.47	[2].490	1.48	3.99	8.7	26.9
May 14	......	......	56.8	56.1	8.69	443.2	3.65	186.1	629.3	5.99	......	4.89	......	1.40	3.49	7.9	29.6
	......	......	54.9	54.3	8.40	428.4	3.52	179.5	607.9	5.86	......	4.76	......	1.36	3.40	7.9	29.6
	......	......	54.8	54.2	8.38	427.4	3.52	179.5	606.9	5.83	......	4.73	......	1.36	3.37	7.9	29.6
	......	......	55.3	54.7	8.46	431.5	3.51	179.0	610.5	5.81	......	4.71	......	1.37	3.34	7.7	30.4
	......	......	55.2	54.6	8.45	431.0	3.58	182.6	613.6	5.70	......	4.60	......	1.37	3.23	7.5	31.2
Average	51.0	15.3	55.4	54.8	8.48	432.3	3.56	181.3	613.6	5.85	[1]1.10	4.75	[2].490	1.37	3.38	7.8	30.0
May 17	......	......	57.7	57.0	8.83	445.0	3.80	191.5	636.5	6.35	......	5.25	......	1.41	3.84	8.6	27.2
	......	......	58.2	57.5	8.90	448.6	4.11	207.1	655.7	6.30	......	5.20	......	1.42	3.78	8.4	27.8
	......	......	57.6	56.9	8.81	444.0	4.09	206.1	650.1	6.28	......	5.18	......	1.41	3.77	8.5	27.5
	......	......	57.6	56.9	8.81	444.0	4.03	203.1	647.1	6.25	......	5.15	......	1.41	3.74	8.4	27.9
	......	......	57.6	56.9	8.81	444.0	4.12	207.6	651.6	6.33	......	5.23	......	1.41	3.82	8.5	27.5
Average	50.4	15.3	57.7	57.0	8.83	445.1	4.03	203.1	648.2	6.30	[1]1.10	5.20	[2].490	1.41	3.79	8.5	27.5

May 18	......	......	60.3	59.6	9.29	476.6	4.22	216.5	693.1	6.41	......	5.31	......	1.50	3.81	8.0	29.3
	......	......	60.2	59.5	9.27	475.6	4.24	217.5	693.1	6.46	......	5.36	......	1.50	3.86	8.1	28.9
	......	......	60.1	59.4	9.26	475.0	4.28	219.6	694.6	6.48	......	5.38	......	1.50	3.88	8.2	28.5
	......	......	59.6	58.9	9.18	470.9	4.00	205.2	676.1	6.37	......	5.27	......	1.48	3.79	8.0	29.3
	......	......	59.3	58.6	9.13	468.4	3.84	197.0	665.4	6.28	......	5.18	......	1.48	3.70	7.9	30.4
	......	......	58.7	58.0	9.04	463.8	3.82	196.0	659.8	6.33	......	5.23	......	1.46	3.77	8.1	28.9
Average	51.3	15.4	59.7	59.0	9.20	471.7	4.07	208.6	680.4	6.38	[1]1.10	5.28	[2].490	1.49	3.79	8.0	29.3
May 24	......	......	65.5	64.7	10.02	509.0	4.48	227.6	736.6	7.19	......	6.09	......	1.61	4.48	8.8	26.6
	......	......	65.6	64.8	10.04	510.0	4.72	239.8	749.8	7.27	......	6.17	......	1.62	4.55	8.9	26.3
	......	......	65.7	64.9	10.05	510.5	4.94	251.0	761.5	7.00	......	5.90	......	1.62	4.28	8.4	27.8
	......	......	66.0	65.2	10.10	513.1	4.90	248.9	762.0	7.07	......	5.97	......	1.63	4.34	8.5	27.5
	......	......	66.3	65.5	10.14	515.1	4.87	247.4	762.5	6.96	......	5.86	......	1.63	4.23	8.2	28.5
	......	......	66.6	65.8	10.19	517.6	4.92	249.9	767.5	7.19	......	6.09	......	1.64	4.45	8.6	27.2
Average	50.8	15.3	66.0	65.2	10.09	512.6	4.81	244.1	756.7	7.14	[1]1.10	6.04	[2].490	1.63	4.41	8.6	27.2
May 25	......	......	66.4	65.6	10.16	519.2	4.37	223.3	742.5	7.19	......	6.09	......	1.65	4.44	8.6	27.2
	......	......	67.4	66.6	10.31	526.8	4.74	242.2	769.0	7.34	......	6.24	......	1.67	4.57	8.7	26.9
	......	......	66.9	66.1	10.24	523.3	4.88	249.4	772.7	7.25	......	6.15	......	1.66	4.49	8.6	27.2
	......	......	66.8	66.0	10.22	522.2	4.82	246.3	768.5	7.24	......	6.14	......	1.66	4.48	8.6	27.2
	......	......	66.6	65.8	10.19	520.7	4.74	242.2	762.9	7.17	......	6.07	......	1.65	4.42	8.5	27.5
	......	......	66.5	65.7	10.17	519.7	4.68	239.2	758.9	7.05	......	5.95	......	1.65	4.30	8.3	28.2
Average	51.1	15.3	66.8	66.0	10.22	522.0	4.71	240.4	762.4	7.23	[1]1.10	6.13	[2].490	1.66	4.47	8.6	27.2
May 26	......	......	77.6	76.7	11.87	614.9	4.02	208.2	823.1	8.24	......	7.14	......	1.95	5.19	8.4	27.8
	......	......	78.9	78.0	12.07	625.2	4.44	230.0	855.2	8.99	......	7.89	......	1.98	5.91	9.4	24.9
	......	......	79.2	78.3	12.12	627.8	4.26	220.7	848.5	8.55	......	7.45	......	1.99	5.46	8.7	26.9
	......	......	79.7	78.8	12.19	631.4	4.28	221.7	853.1	9.28	......	8.18	......	2.00	6.18	9.8	23.9
	......	......	80.3	79.4	12.29	636.6	4.29	222.2	858.8	9.21	......	8.11	......	2.02	6.09	9.5	24.7
	......	......	80.7	79.8	12.35	639.7	4.09	211.9	851.6	8.80	......	7.70	......	2.03	5.67	8.9	26.3
Average	51.8	15.3	79.4	78.5	12.15	629.3	4.23	219.1	848.4	8.82	[1]1.10	7.72	[2].490	2.00	5.72	9.1	25.7
May 28	......	......	78.1	77.2	11.95	610.6	4.59	234.5	845.1	8.09	......	6.99	......	1.94	5.05	8.3	28.2
	......	......	78.9	78.0	12.07	616.8	4.35	222.3	839.1	8.11	......	7.01	......	1.96	5.05	8.2	28.5
	......	......	79.4	78.5	12.15	620.9	4.51	230.5	851.4	8.25	......	7.13	......	1.97	5.16	8.3	28.2
	......	......	79.8	78.9	12.21	623.9	4.52	231.0	854.9	8.31	......	7.21	......	1.98	5.23	8.4	27.8
	......	......	80.7	79.8	12.35	631.1	4.67	238.6	869.7	8.53	......	7.43	......	2.00	5.43	8.6	27.2
	......	......	80.9	80.0	12.38	632.6	4.68	239.2	871.8	8.68	......	7.58	......	2.01	5.57	8.8	26.6
Average	51.1	15.3	79.6	78.7	12.19	622.7	4.55	232.7	855.3	8.33	[1]1.10	7.23	[2].490	1.97	5.26	8.4	27.8
May 29	......	......	79.0	78.1	12.09	621.4	4.73	243.1	864.5	8.28	......	7.15	......	1.97	5.18	8.3	28.2
	......	......	80.0	79.1	12.24	629.1	4.79	246.2	875.3	8.48	......	7.35	......	2.00	5.35	8.5	27.5
	......	......	80.4	79.5	12.30	632.2	5.77	296.6	928.8	8.65	......	7.52	......	2.01	5.51	8.7	26.9
Average	51.4	15.3	79.8	78.9	12.21	627.6	5.10	262.0	889.5	8.45	[3]1.13	7.32	[2].490	1.99	5.33	8.5	27.5
June 1	......	......	80.6	79.7	12.33	632.5	4.73	242.7	875.2	8.42	......	7.37	......	2.01	5.36	8.4	27.8
	......	......	80.2	79.3	12.27	629.4	5.03	258.0	887.4	8.61	......	7.56	......	2.00	5.56	8.8	26.6
	......	......	80.6	79.7	12.33	632.5	5.05	259.1	891.6	8.69	......	7.64	......	2.01	5.63	8.9	26.3
Average	51.3	15.3	80.5	79.6	12.31	631.5	4.94	253.3	883.7	8.56	[3]1.05	7.51	[2].490	2.00	5.51	8.7	26.9

---

[1] General average of values obtained with subject in all standing experiments. See last column of table 5, p. 44.
[2] General average for this subject of increments in the heat per horizontal kilogrammeter in horizontal walking. See column *i*, table 31, p. 123.
[3] Average for the day. See last column of table 5, p. 44.

TABLE 54.—*Increase in the heat-output of W. K. during grade walking in experiments without food. (Values per minute.)*—Continued.

Subject and date.	(a) Body-weight with clothing.	(b) Grade.	(c) Distance walked.	(d) Horizontal component of distance.	(e) Grade-lift of body. (b × c)	(f) Work due to grade-lift. (e × a)	(g) Step-lift.	(h) Work due to step-lift. (g × a)	(i) Work of total lift (work of ascent). (f + h)	(j) Total heat during grade walking (computed).	(k) Heat due to standing.	(l) Increment over standing requirement. (j − k)	Heat due to horizontal component. (m) Per horizontal kilogrammeter.	Heat due to horizontal component. (n) Total. $\frac{d \times a \times m}{1,000}$	Increment in heat over standing and horizontal components due to grade-lift. (o) Total. (l − n)	Increment in heat over standing and horizontal components due to grade-lift. (p) Per kg. m. of grade-lift. $\frac{o \times 1,000}{f}$	(q) Efficiency for grade-lift. $\frac{2.34 \times 100}{p}$
	kg.	*p. ct.*	*meters.*	*meters.*	*meters.*	*kg. m.*	*meters.*	*kg. m.*	*kg. m.*	*cals.*	*cals.*	*cals.*	*gm.-cal.*	*cals.*	*cals.*	*gm.-cals.*	*p. ct.*
June 2	......	......	79.1	78.2	12.10	624.4	4.73	244.1	868.5	8.42	......	7.31	......	1.98	5.33	8.5	27.5
	......	......	79.8	78.9	12.21	630.0	5.07	261.6	891.6	8.49	......	7.38	......	2.00	5.38	8.5	27.5
	......	......	80.4	79.5	12.30	634.7	5.27	271.9	906.6	8.71	......	7.60	......	2.01	5.59	8.8	26.6
Average	51.6	15.3	79.8	78.9	12.20	629.7	5.02	259.2	888.9	8.52	[1]1.11	7.41	[2]0.490	2.00	5.41	8.6	27.2
June 7	......	......	49.9	48.9	9.98	513.0	4.03	207.1	720.1	6.78	......	5.68	......	1.23	4.45	8.7	26.9
	......	......	50.1	49.1	10.02	515.0	4.08	209.7	724.7	6.91	......	5.81	......	1.24	4.57	8.9	26.3
	......	......	48.8	47.8	9.76	501.7	4.05	208.2	709.9	6.72	......	5.62	......	1.21	4.41	8.8	26.6
	......	......	47.9	46.9	9.58	492.4	3.86	198.4	690.8	6.50	......	5.40	......	1.18	4.22	8.6	27.2
	......	......	47.8	46.8	9.56	491.4	3.90	200.5	691.9	6.58	......	5.48	......	1.18	4.30	8.8	26.6
	......	......	47.3	46.3	9.46	486.2	4.00	205.6	691.8	6.67	......	5.57	......	1.17	4.40	9.1	25.7
Average	51.4	20.0	48.6	47.6	9.73	500.0	3.99	204.9	704.9	6.69	[1]1.10	5.59	[2].490	1.20	4.39	8.8	26.6
June 8	......	......	46.7	45.8	9.34	477.3	3.69	188.6	665.9	6.38	......	5.28	......	1.15	4.13	8.7	26.9
	......	......	45.1	44.2	9.02	460.9	3.62	185.0	645.9	6.25	......	5.15	......	1.11	4.04	8.8	26.6
	......	......	43.9	43.0	8.78	448.7	3.60	184.0	632.7	6.11	......	5.01	......	1.08	3.93	8.8	26.6
	......	......	50.5	49.5	10.10	516.1	4.35	222.3	738.4	6.92	......	5.82	......	1.24	4.58	8.9	26.3
	......	......	50.4	49.4	10.08	515.1	4.45	227.4	742.5	7.07	......	5.97	......	1.24	4.73	9.4	24.9
	......	......	50.0	49.0	10.00	511.0	4.53	231.5	742.5	7.14	......	6.04	......	1.23	4.81	9.4	24.9
Average	51.1	20.0	47.8	46.8	9.55	488.2	4.04	206.5	694.7	6.64	[1]1.10	5.54	[2].490	1.17	4.37	8.9	26.3
June 9	......	......	57.3	56.1	11.46	570.7	4.97	247.5	818.2	7.53	......	6.43	......	1.37	5.06	8.9	26.3
	......	......	56.9	55.8	11.38	566.7	4.94	246.0	812.7	7.44	......	6.34	......	1.36	4.98	8.8	26.6
	......	......	56.9	55.8	11.38	566.7	5.39	268.4	835.1	7.65	......	6.55	......	1.36	5.19	9.1	25.7
	......	......	58.0	56.8	11.60	577.7	5.33	265.4	843.1	7.88	......	6.78	......	1.39	5.39	9.4	24.9
	......	......	57.0	55.8	11.40	567.7	5.01	249.5	817.2	7.73	......	6.62	......	1.36	5.26	9.3	25.2
	......	......	57.0	55.8	11.40	567.7	5.33	265.4	833.1	7.70	......	6.60	......	1.36	5.24	9.2	25.4
Average	49.8	20.0	57.2	56.0	11.44	569.5	5.16	257.0	826.6	7.65	[1]1.10	6.55	[2].490	1.37	5.18	9.1	25.7

June 10	......	......	63.4	62.1	12.68	632.7	5.76	287.4	920.1	8.34	......	7.24	......	1.52	5.72	9.0	26.0
	......	......	63.0	61.7	12.60	628.7	5.97	297.9	926.6	8.43	......	7.33	......	1.51	5.82	9.2	25.4
	......	......	62.9	61.6	12.58	627.7	6.06	302.4	930.1	8.40	......	7.30	......	1.51	5.79	9.2	25.4
	......	......	64.0	62.7	12.80	638.7	6.13	305.9	944.6	8.57	......	7.47	......	1.54	5.93	9.3	25.2
	......	......	63.8	62.5	12.76	636.7	6.25	311.9	948.6	8.55	......	7.45	......	1.53	5.92	9.3	25.2
	......	......	63.4	62.1	12.68	632.7	5.93	295.9	928.6	8.49	......	7.39	......	1.52	5.87	9.3	25.2
Average	49.9	20.0	63.4	62.1	12.68	632.9	6.02	300.2	933.1	8.45	[3]1.10	7.35	[2].490	1.52	5.83	9.2	25.4
June 11	......	......	73.2	71.7	14.64	734.9	7.17	359.9	1,094.8	9.68	......	8.58	......	1.77	6.81	9.2	25.4
	......	......	73.4	71.9	14.68	736.9	7.27	365.0	1,101.9	9.76	......	8.66	......	1.77	6.89	9.3	25.2
	......	......	74.0	72.5	14.80	743.0	7.45	374.0	1,117.0	9.81	......	8.71	......	1.79	6.92	9.3	25.2
	......	......	69.0	67.6	13.80	692.8	6.65	333.8	1,026.6	9.13	......	8.03	......	1.67	6.36	9.2	25.4
	......	......	68.3	66.9	13.66	685.7	6.56	329.3	1,015.0	9.14	......	8.04	......	1.65	6.39	9.3	25.2
Average	50.2	20.0	71.6	70.1	14.32	718.7	7.02	352.4	1,071.1	9.51	[3]1.10	8.41	[2].490	1.73	6.68	9.3	25.2
June 12	......	......	73.5	72.0	14.70	739.4	6.47	325.4	1,064.8	9.52	......	8.42	......	1.78	6.64	9.0	26.0
	......	......	74.6	73.1	14.92	750.5	6.82	343.0	1,093.5	9.87	......	8.77	......	1.81	6.96	9.3	25.2
	......	......	74.4	72.9	14.88	748.5	6.42	322.9	1,071.4	9.79	......	8.69	......	1.80	6.89	9.2	25.4
	......	......	74.0	72.5	14.80	744.4	6.42	322.9	1,067.3	9.57	......	8.47	......	1.79	6.68	9.0	26.0
	......	......	74.0	72.5	14.80	744.4	6.78	341.0	1,085.4	9.62	......	8.52	......	1.79	6.73	9.0	26.0
	......	......	74.0	72.5	14.80	744.4	6.67	335.5	1,079.9	9.73	......	8.63	......	1.79	6.84	9.2	25.4
Average	50.3	20.0	74.1	72.6	14.82	745.3	6.60	331.8	1,077.1	9.69	[3]1.10	8.59	[2].490	1.79	6.80	9.1	25.7
June 14	......	......	78.8	77.2	15.76	792.7	6.53	328.5	1,121.2	9.97	......	8.94	......	1.91	7.03	8.9	26.3
	......	......	79.8	78.2	15.96	802.8	7.04	354.1	1,156.9	10.18	......	9.15	......	1.93	7.22	9.0	26.0
	......	......	80.0	78.4	16.00	804.8	7.04	354.1	1,158.9	10.37	......	9.34	......	1.94	7.40	9.2	25.4
Average	50.3	20.0	79.5	77.9	15.91	800.1	6.87	345.6	1,145.7	10.16	[1]1.03	9.13	[2].490	1.92	7.21	9.0	26.0
June 15	......	......	57.2	55.4	14.30	722.2	5.07	256.0	978.2	9.00	......	7.90	......	1.37	6.53	9.0	26.0
	......	......	55.0	53.3	13.75	694.4	4.59	231.8	926.2	8.62	......	7.52	......	1.32	6.20	8.9	26.3
	......	......	54.6	52.9	13.65	689.3	4.33	218.7	908.0	8.56	......	7.46	......	1.31	6.15	8.9	26.3
	......	......	54.4	52.7	13.60	686.8	4.16	210.1	896.9	8.46	......	7.36	......	1.31	6.05	8.8	26.6
	......	......	53.1	51.4	13.27	670.1	4.22	213.1	883.2	8.42	......	7.32	......	1.27	6.05	9.0	26.0
	......	......	53.1	51.4	13.27	670.1	4.11	207.6	877.7	8.40	......	7.30	......	1.27	6.03	9.0	26.0
Average	50.5	25.0	54.6	52.9	13.64	688.8	4.41	222.9	911.7	8.58	[3]1.10	7.48	[2].490	1.31	6.17	9.0	26.0
June 16	......	......	59.9	58.0	14.97	753.0	4.93	248.0	1,001.0	9.34	......	8.24	......	1.43	6.81	9.0	26.0
	......	......	58.7	56.8	14.67	737.9	4.14	208.2	946.1	9.12	......	8.02	......	1.40	6.62	8.9	26.3
	......	......	57.4	55.6	14.35	721.8	4.13	207.7	929.5	8.98	......	7.88	......	1.37	6.51	9.0	26.0
	......	......	51.8	49.2	12.95	651.4	3.64	183.1	834.5	8.24	......	7.14	......	1.22	5.92	9.1	25.7
	......	......	50.9	49.3	12.72	639.8	3.34	168.0	807.8	8.00	......	6.90	......	1.22	5.68	8.9	26.3
	......	......	50.1	48.5	12.52	629.8	3.39	170.5	800.3	7.89	......	6.79	......	1.20	5.59	8.9	26.3
Average	50.3	25.0	54.8	52.9	13.70	689.0	3.93	197.6	886.5	8.58	[3]1.10	7.48	[2].490	1.31	6.17	9.0	26.0

---

[1] Average for the day. See last column of table 5, p. 44.
[2] General average for this subject of increments in the heat per horizontal kilogrammeter in horizontal walking. See column *i*, table 31, p. 123.
[3] General average of values obtained with subject in all standing experiments. See last column of table 5, p. 44.

TABLE 54.—*Increase in the heat-output of W. K. during grade walking in experiments without food. (Values per minute.)*—Continued.

Subject and date.	(a) Body-weight with clothing.	(b) Grade.	(c) Distance. walked.	(d) Horizontal component of distance.	(e) Grade-lift of body. (b × c)	(f) Work due to grade-lift. (e × a)	(g) Step-lift.	(h) Work due to step-lift. (g × a)	(i) Work of total lift (work of ascent). (f + h)	(j) Total heat during grade walking (computed).	(k) Heat due to standing.	(l) Increment over standing requirement. (j − k)	Heat due to horizontal component.		Increment in heat over standing and horizontal components due to grade-lift.		(q) Efficiency for grade-lift. $\frac{2.34 \times 100}{p}$
													(m) Per horizontal kilogrammeter.	(n) Total. $\frac{d \times a \times m}{1,000}$	(o) Total. (l − n)	(p) Per kg. m. of grade-lift. $\frac{o \times 1,000}{f}$	
	kg.	*p. ct.*	*meters.*	*meters.*	*meters.*	*kg. m.*	*meters.*	*kg. m.*	*kg. m.*	*cals.*	*cals.*	*cals.*	*gm.-cal.*	*cals.*	*cals.*	*gm.-cals*	*p. ct.*
June 17..........	....	......	67.6	65.5	16.90	851.8	5.67	285.8	1,137.6	10.51	....	9.41	....	1.62	7.79	9.1	25.7
	....	......	66.8	64.7	16.70	841.7	5.34	269.1	1,110.8	10.39	....	9.29	....	1.60	7.69	9.1	25.7
	....	......	66.4	64.3	16.60	836.6	5.37	270.6	1,107.2	10.30	....	9.20	....	1.59	7.61	9.1	25.7
	....	......	66.6	64.5	16.65	839.2	5.71	287.8	1,127.0	10.36	....	9.26	....	1.60	7.66	9.2	25.4
Average.....	50.4	25.0	66.9	64.8	16.71	842.3	5.52	278.3	1,120.7	10.38	[1]1.10	9.28	[2]0.490	1.60	7.68	9.1	25.7
June 23..........	....	......	70.5	68.3	17.62	879.2	6.20	309.4	1,188.6	10.32	....	9.22	....	1.39	7.83	8.9	26.3
	....	......	72.4	70.1	18.10	903.2	6.18	308.4	1,211.6	10.81	....	9.71	....	1.43	8.28	9.2	25.4
Average.....	49.9	25.0	71.5	69.2	17.86	891.2	6.19	308.9	1,200.1	10.57	[1]1.10	9.47	[3].409	1.41	8.06	9.1	25.7

[1] General average of values obtained with subject in all standing experiments. See last column of table 5, p. 44.

[2] General average for this subject of increments in the heat per horizontal kilogrammeter in horizontal walking. See column *i*, table 31, p. 123.

[3] Average for the day. See column *i*, table 31, p. 123.

TABLE 55.—*Increase in the heat-output of E. D. B. during grade walking in experiments without food. (Values per minute.)*

Subject and date.	(a) Body-weight with clothing.	(b) Grade.	(c) Distance walked.	(d) Horizontal component of distance.	(e) Grade-lift of body. (b × c)	(f) Work due to grade-lift. (e × a)	(g) Step-lift.	(h) Work due to step-lift. (g × a)	(i) Work of total lift (work of ascent). (f + h)	(j) Total heat during grade walking (computed).	(k) Heat due to standing.	(l) Increment over standing requirement. (j − k)	Heat due to horizontal component. (m) Per h.kg.m.	Heat due to horizontal component. (n) Total. $\frac{d \times a \times m}{1,000}$	Increment in heat over standing and horizontal components due to grade-lift. (o) Total. (l − n)	Increment in heat over standing and horizontal components due to grade-lift. (p) Per kg. m. of grade-lift. $\frac{o \times 1,000}{f}$	(q) Efficiency for grade-lift. $\frac{2.34 \times 100}{p}$
1915	*kg.*	*p. ct.*	*meters.*	*meters.*	*meters.*	*kg. m.*	*meters.*	*kg. m.*	*kg. m.*	*cals.*	*cals.*	*cals.*	*gm.-cal.*	*cals.*	*cals.*	*gm.-cals.*	*p. ct.*
Oct. 30			39.8	39.6	1.99	116.8	0.94	55.2	172.0	2.89		1.81		1.15	0.66	5.6	41.8
			38.4	38.4	1.92	112.7	.90	52.8	165.5	2.89		1.81		1.12	.69	6.1	38.4
			37.9	37.9	1.90	111.5	.84	49.3	160.8	2.86		1.78		1.10	.68	6.1	38.4
			37.9	37.9	1.90	111.5	.86	50.5	162.0	2.91		1.83		1.10	.73	6.5	36.0
Average	58.7	5.0	38.5	38.5	1.93	113.1	.89	52.0	165.1	2.89	[1]1.08	1.81	[2]0.496	1.12	.69	6.1	38.4
Nov. 1			49.4	49.3	2.47	145.7	1.37	80.8	226.5	3.19		2.11		1.38	.73	5.0	46.8
			48.8	48.7	2.44	144.0	1.34	79.1	223.1	3.17		2.09		1.36	.73	5.1	45.8
			48.6	48.5	2.43	143.4	1.32	77.9	221.3	3.22		2.14		1.36	.78	5.5	42.5
			47.8	47.7	2.39	141.0	1.36	80.2	221.2	3.26		2.18		1.33	.85	6.0	39.0
Average	59.0	5.0	48.7	48.6	2.43	143.5	1.35	79.5	223.0	3.21	[1]1.08	2.13	[2].474	1.36	.77	5.4	43.4
Nov. 2			41.0	40.9	2.05	120.3	1.01	59.3	179.6	2.99		1.91		1.17	.74	6.2	37.8
			40.5	40.4	2.03	119.2	1.02	59.9	179.1	2.97		1.89		1.16	.73	6.1	38.4
			40.4	40.3	2.02	118.6	1.08	63.4	182.0	3.04		1.96		1.16	.80	6.7	35.0
			41.7	41.6	2.09	122.7	1.12	65.7	188.4	3.01		1.93		1.20	.73	5.9	39.7
Average	58.7	5.0	40.9	40.8	2.05	120.2	1.06	62.1	182.3	3.00	[1]1.08	1.92	[2].489	1.17	.75	6.3	37.2
Nov. 3			43.1	43.0	2.16	127.2	.90	53.0	180.2	2.99		1.91		1.14	.77	6.1	38.4
			42.3	42.2	2.12	124.9	.80	47.1	172.2	2.98		1.90		1.11	.79	6.3	37.2
			42.1	42.0	2.11	124.3	.90	53.0	177.3	3.00		1.92		1.11	.81	6.5	36.0
			41.5	41.4	2.08	122.5	.94	55.4	177.9	3.01		1.93		1.10	.83	6.8	34.4
Average	58.9	5.0	42.3	42.2	2.12	124.7	.89	52.1	176.9	2.99	[1]1.08	1.91	[2].450	1.11	.80	6.4	36.6
Nov. 4			48.3	48.2	2.42	141.1	.98	57.1	198.2	3.18		2.10		1.26	.84	6.0	39.0
			48.5	48.4	2.43	141.7	1.08	63.0	204.7	3.15		2.07		1.26	.81	5.7	41.1
			48.1	48.0	2.41	140.5	.94	54.8	195.3	3.11		2.03		1.25	.78	5.5	42.5
			47.7	47.6	2.39	139.3	.94	54.8	194.1	3.17		2.09		1.24	.85	6.1	38.4
Average	58.3	5.0	48.2	48.1	2.41	140.7	.99	57.4	198.1	3.16	[1]1.08	2.08	[2].447	1.25	.83	5.9	39.7

[1] Average of values obtained with subject standing, in experiments without food between October 11 and December 22, 1915, inclusive. See last column of table 6, p. 46.

[2] Average for the day. See column *i*, table 32, p. 126.

TABLE. 55.—*Increase in the heat-output of E. D. B. during grade walking in experiments without food.* (*Values per minute.*)—Continued.

Subject and date.	(*a*) Body-weight with clothing.	(*b*) Grade.	(*c*) Distance walked.	(*d*) Horizontal component of distance.	(*e*) Grade-lift of body. $(b \times c)$	(*f*) Work due to grade-lift. $(e \times a)$	(*g*) Step-lift.	(*h*) Work due to step-lift. $(g \times a)$	(*i*) Work of total lift (work of ascent). $(f + h)$	(*j*) Total heat during grade walking (computed).	(*k*) Heat due to standing.	(*l*) Increment over standing requirement. $(j - k)$	Heat due to horizontal component.		Increment in heat over standing and horizontal components due to grade-lift.		(*q*) Efficiency for grade-lift. $\frac{2.34 \times 100}{p}$
													(*m*) Per h.k.gm.	(*n*) Total. $\frac{d \times a \times m}{1,000}$	(*o*) Total. $(l - n)$	(*p*) Per kg. m. of grade-lift. $\frac{o \times 1000}{f}$	
1915	*kg.*	*p. ct.*	*meters.*	*meters.*	*meters.*	*kg. m.*	*meters.*	*kg. m.*	*kg. m.*	*cals.*	*cals.*	*cals.*	*gm.-cal.*	*cals.*	*cals.*	*gm.-cals.*	*p. ct.*
Nov. 5	......	......	44.0	43.9	2.20	128.5	.85	49.6	178.1	2.97	......	1.89	......	1.18	0.71	5.5	42.5
	......	......	42.6	42.5	2.13	124.4	.87	50.8	175.2	2.99	......	1.91	......	1.14	.77	6.2	37.8
	......	......	41.3	41.2	2.07	120.9	.80	46.6	167.5	2.98	......	1.90	......	1.11	.79	6.5	36.0
	......	......	42.0	41.9	2.10	122.6	.78	45.5	168.1	3.00	......	1.92	......	1.13	.79	6.4	36.6
Average	58.4	5.0	42.5	42.4	2.13	124.1	.83	48.1	172.2	2.98	[1]1.08	1.90	[2]0.460	1.14	.76	6.1	38.4
Nov. 6	......	......	49.5	49.4	2.48	145.6	1.07	62.8	208.4	3.04	......	1.96	......	1.26	.70	4.8	48.7
	......	......	49.1	49.0	2.46	144.4	1.06	62.2	206.6	3.14	......	2.06	......	1.25	.81	5.6	41.8
	......	......	47.9	47.8	2.40	140.9	.99	58.0	198.9	3.04	......	1.96	......	1.22	.74	5.3	44.2
	......	......	47.9	47.8	2.40	140.9	.98	57.5	198.4	2.99	......	1.91	......	1.22	.69	4.9	47.8
	......	......	46.7	46.6	2.34	137.4	.92	54.0	191.4	3.06	......	1.98	......	1.19	.79	5.8	40.4
Average	58.7	5.0	48.2	48.1	2.42	141.8	1.00	58.9	200.7	3.06	[1]1.08	1.98	[2].435	1.23	.75	5.3	44.2
Nov. 8	......	......	53.5	53.4	2.68	158.1	1.27	74.9	233.0	3.25	......	2.17	......	1.42	.75	4.7	49.8
	......	......	52.3	52.2	2.62	154.6	1.20	70.8	225.4	3.22	......	2.14	......	1.39	.75	4.8	48.7
	......	......	52.3	52.2	2.62	154.6	1.18	69.6	224.2	3.28	......	2.20	......	1.39	.81	5.2	45.0
	......	......	51.8	51.7	2.59	152.8	1.24	73.2	226.0	3.24	......	2.16	......	1.37	.79	5.2	45.0
Average	59.0	5.0	52.5	52.4	2.63	155.0	1.22	72.1	227.2	3.25	[1]1.08	2.17	[2].451	1.39	.78	5.0	46.8
Nov. 9	......	......	55.6	55.5	2.78	163.5	1.52	89.4	252.9	3.34	......	2.26	......	1.37	.89	5.4	43.4
	......	......	54.9	54.8	2.75	161.7	1.35	79.4	241.1	3.27	......	2.19	......	1.35	.84	5.2	45.0
	......	......	54.6	54.5	2.73	160.5	1.34	78.8	239.3	3.37	......	2.29	......	1.35	.94	5.8	40.4
	......	......	53.9	53.8	2.70	158.8	1.38	81.1	239.9	3.31	......	2.23	......	1.33	.90	5.9	39.7
Average	58.8	5.0	54.8	54.7	2.74	161.1	1.40	82.2	243.3	3.32	[1]1.08	2.24	[2].420	1.35	.89	5.5	42.5
Nov. 10	......	......	57.3	57.2	2.87	168.8	1.35	79.4	248.2	3.33	......	2.25	......	1.49	.76	4.5	52.0
	......	......	56.5	56.4	2.83	166.4	1.42	83.5	249.9	3.36	......	2.28	......	1.47	.81	4.9	47.8
	......	......	54.0	53.9	2.70	158.8	1.42	83.5	242.3	3.23	......	2.15	......	1.40	.75	4.7	49.8
	......	......	53.7	53.6	2.69	158.2	1.36	80.0	238.2	3.16	......	2.08	......	1.40	.68	4.3	54.4
Average	58.8	5.0	55.4	55.3	2.77	163.1	1.39	81.6	244.7	3.27	[1]1.08	2.19	[2].443	1.40	.79	4.8	48.7

Nov. 11	......	......	67.1	67.0	3.36	197.9	......	......	......	3.74	......	2.66	......	1.62	1.04	5.3	44.2
	......	......	65.8	65.7	3.29	193.8	......	......	......	3.75	......	2.67	......	1.74	.93	4.8	48.7
	......	......	65.9	65.8	3.30	194.4	1.83	107.8	302.2	3.80	......	2.72	......	1.75	.97	5.0	46.8
	......	......	65.3	65.2	3.27	192.6	1.77	104.3	296.9	3.88	......	2.80	......	1.73	1.07	5.6	41.8
Average......	58.9	5.0	66.0	65.9	3.31	194.7	1.80	106.1	299.6	3.80	[1]1.08	2.72	[2].452	1.76	.96	4.9	47.8
Nov. 12	......	......	65.6	65.5	3.28	192.9	1.97	115.8	308.7	3.71	......	2.63	......	1.77	.86	4.5	52.0
	......	......	65.4	65.3	3.27	192.3	1.88	110.5	302.8	3.85	......	2.77	......	1.76	1.01	5.3	44.2
	......	......	65.7	65.6	3.29	193.5	1.75	102.9	296.4	3.79	......	2.71	......	1.77	.94	4.9	47.8
	......	......	64.8	64.7	3.24	190.5	1.22	71.7	262.2	3.79	......	2.71	......	1.75	.96	5.0	46.8
Average.....	58.8	5.0	65.4	65.3	3.27	192.3	1.71	100.2	292.5	3.78	[1]1.08	2.70	[2].459	1.76	.94	4.9	47.8
Nov. 13	......	......	74.0	73.9	3.70	217.2	2.62	153.8	371.0	4.18	......	3.10	......	1.97	1.13	5.2	45.0
	......	......	74.1	74.0	3.71	217.8	2.59	152.0	369.8	4.32	......	3.24	......	1.97	1.27	5.8	40.4
	......	......	74.0	73.9	3.70	217.2	2.67	156.7	373.9	4.27	......	3.19	......	1.97	1.22	5.6	41.8
	......	......	74.2	74.1	3.71	217.8	2.87	168.5	386.3	4.14	......	3.06	......	1.98	1.08	5.0	46.8
Average.....	58.7	5.0	74.1	74.0	3.71	217.5	2.69	157.8	375.3	4.24	[1]1.08	3.16	[2].455	1.97	1.19	5.4	43.4
Nov. 15	......	......	74.8	74.7	3.74	221.8	2.72	161.3	383.1	4.19	......	3.11	......	2.04	1.07	4.8	48.7
	......	......	75.0	74.9	3.75	222.4	2.77	164.3	386.7	4.27	......	3.19	......	2.05	1.14	5.1	45.8
	......	......	75.0	74.9	3.75	222.4	2.61	154.8	377.2	4.29	......	3.21	......	2.05	1.16	5.2	45.0
	......	......	75.1	75.0	3.76	223.0	2.71	160.7	383.7	4.29	......	3.21	......	2.04	1.17	5.3	44.2
Average.....	59.3	5.0	75.0	74.9	3.75	222.4	2.70	160.3	382.7	4.26	[1]1.08	3.18	[2].460	2.05	1.13	5.1	45.8
Nov. 16	......	......	70.1	70.0	3.51	206.0	2.40	140.9	346.9	3.99	......	2.91	......	1.91	1.00	4.9	47.8
	......	......	75.1	75.0	3.76	220.7	2.61	153.2	373.9	4.18	......	3.10	......	2.04	1.06	4.7	49.8
	......	......	75.3	75.2	3.67	215.4	2.73	160.2	375.6	4.19	......	3.11	......	2.04	1.07	4.8	48.7
	......	......	74.7	74.6	3.74	219.5	2.51	147.3	366.8	4.19	......	3.11	......	2.04	1.07	4.7	49.8
Average.....	58.7	5.0	73.8	73.7	3.47	215.4	2.56	150.4	365.8	4.14	[1]1.08	3.06	[2].464	2.01	1.05	4.9	47.8
Nov. 17	......	......	48.7	48.4	5.02	294.2	1.93	113.1	407.3	4.24	......	3.16	......	1.28	1.88	6.4	36.6
	......	......	48.5	48.2	5.00	293.0	1.89	110.7	403.7	4.30	......	3.22	......	1.28	1.94	6.6	35.4
	......	......	47.6	47.3	4.90	287.1	1.80	105.5	392.6	4.28	......	3.20	......	1.25	1.95	6.8	34.4
	......	......	47.3	47.0	4.87	285.4	1.82	106.7	392.1	4.31	......	3.23	......	1.25	1.98	7.0	33.4
Average.....	58.6	10.3	48.0	47.7	4.95	289.9	1.86	109.0	398.9	4.28	[1]1.08	3.20	[2].452	1.27	1.93	6.7	35.0
Nov. 22	......	......	42.5	42.3	4.38	255.4	1.56	90.9	346.3	3.85	......	2.77	......	1.14	1.63	6.4	36.6
	......	......	41.5	41.3	4.27	248.9	1.51	88.0	336.9	3.85	......	2.77	......	1.11	1.66	6.7	35.0
	......	......	41.5	41.3	4.27	248.9	1.63	95.0	343.9	3.93	......	2.85	......	1.11	1.74	7.0	33.4
	......	......	41.5	41.3	4.27	248.9	1.67	97.4	346.3	3.98	......	2.90	......	1.11	1.79	7.2	32.5
Average.....	58.3	10.3	41.8	41.6	4.30	250.5	1.59	92.8	343.4	3.91	[1]1.08	2.83	[2].461	1.12	1.71	6.8	34.4
Nov. 23	......	......	57.8	57.5	5.78	341.0	2.44	144.0	485.0	4.73	......	3.65	......	1.41	2.24	6.6	35.4
	......	......	57.0	56.7	5.70	336.3	2.50	147.5	483.8	4.87	......	3.79	......	1.39	2.40	7.2	32.5
	......	......	57.1	56.8	5.71	336.9	2.55	150.4	487.3	4.85	......	3.77	......	1.39	2.38	7.1	33.0
	......	......	56.8	56.5	5.68	335.1	2.46	145.1	480.2	4.90	......	3.82	......	1.38	2.44	7.3	32.1
Average.....	59.0	10.0	57.2	56.9	5.72	337.3	2.49	146.8	484.1	4.84	[1]1.08	3.76	[2].415	1.39	2.37	7.0	33.4

---

[1] Average of values obtained with subject standing, in experiments without food between October 11 and December 22, 1915, inclusive. See last column of table 6, p. 46.

[2] Average for the day. See column *i*, table 32, p. 126.

TABLE 55.—*Increase in the heat-output of E. D. B. during grade walking in experiments without food.* (*Values per minute.*)—Continued.

Subject and date.	(*a*) Body-weight with clothing.	(*b*) Grade.	(*c*) Distance walked.	(*d*) Horizontal component of distance.	(*e*) Grade-lift of body. ($b\times c$)	(*f*) Work due to grade-lift. ($e\times a$)	(*g*) Step-lift.	(*h*) Work due to step-lift. ($g\times a$)	(*i*) Work of total lift (work of ascent). ($f+h$)	(*j*) Total heat during grade walking (computed).	(*k*) Heat due to standing.	(*l*) Increment over standing requirement. ($j-k$)	Heat due to horizontal component.		Increment in heat over standing and horizontal components due to grade-lift.		(*q*) Efficiency for grade-lift. $\frac{2.34\times 100}{p}$
													(*m*) Per h.kg.m.	(*n*) Total. $\frac{d\times a\times m}{1,000}$	(*o*) Total. $l-n$	(*p*) Per kg. m. of grade-lift. $\frac{o\times 1000}{f}$	
1915.	*kg.*	*p. ct.*	*meters.*	*meters.*	*meters.*	*kg. m.*	*meters.*	*kg. m.*	*kg. m.*	*cals.*	*cals.*	*cals.*	*gm.-cal.*	*cals.*	*cals.*	*gm.-cals.*	*p. ct.*
Nov. 24	......	......	56.5	56.2	5.65	332.8	2.31	136.1	468.9	4.71	......	3.63	......	1.35	2.28	6.9	33.9
	......	......	57.4	57.1	5.74	338.1	2.40	141.4	479.5	4.90	......	3.82	......	1.37	2.45	7.3	32.1
	......	......	58.3	58.0	5.83	343.4	2.64	155.5	498.9	5.01	......	3.93	......	1.39	2.54	7.4	31.7
	......	......	57.4	57.1	5.74	338.1	2.32	136.6	474.7	4.93	......	3.85	......	1.37	2.48	7.3	32.1
Average	58.9	10.0	57.4	57.1	5.74	338.1	2.42	142.4	480.5	4.88	[1]1.08	3.80	[2]0.407	1.37	2.43	7.2	32.5
Nov. 26	......	......	66.1	65.8	6.61	393.3	3.09	183.8	577.1	5.46	......	4.38	......	1.68	2.70	6.9	33.9
	......	......	66.6	66.3	6.66	396.3	3.25	193.4	589.7	5.55	......	4.47	......	1.69	2.78	7.0	33.4
	......	......	66.8	66.5	6.68	397.5	3.36	199.9	597.4	5.67	......	4.59	......	1.70	2.89	7.3	32.1
	......	......	66.6	66.3	6.66	396.3	3.14	186.8	583.1	5.70	......	4.62	......	1.69	2.93	7.4	31.7
Average	59.5	10.0	66.5	66.2	6.65	395.9	3.21	191.0	586.8	5.60	[1]1.08	4.52	[2].429	1.69	2.83	7.2	32.5
Nov. 27	......	......	66.1	65.8	6.61	391.3	2.92	172.9	564.2	5.34	......	4.25	......	1.70	2.55	6.5	36.0
	......	......	65.7	65.4	6.57	388.9	3.04	180.0	568.9	5.48	......	4.39	......	1.70	2.69	6.9	33.9
	......	......	66.0	65.7	6.60	390.7	3.21	190.0	580.7	5.53	......	4.44	......	1.70	2.74	7.0	33.4
	......	......	65.8	65.5	6.58	389.5	3.32	196.5	586.0	5.59	......	4.50	......	1.70	2.80	7.2	32.5
	......	......	65.9	65.6	6.59	390.1	3.46	204.8	594.9	5.64	......	4.55	......	1.70	2.85	7.3	32.1
Average	59.2	10.0	65.9	65.6	6.59	390.1	3.19	188.8	578.9	5.53	[2]1.09	4.44	[3].438	1.70	2.74	7.0	33.4
Nov. 29	......	......	65.6	65.3	6.56	387.7	3.20	189.1	576.8	5.42	......	4.35	......	1.68	2.67	6.9	33.9
	......	......	65.4	65.1	6.54	386.5	3.34	197.4	583.9	5.55	......	4.48	......	1.68	2.80	7.2	32.5
	......	......	65.8	65.5	6.58	388.9	3.40	200.9	589.8	5.68	......	4.64	......	1.69	2.92	7.5	31.2
	......	......	65.6	65.3	6.56	387.7	3.51	207.4	595.1	5.69	......	4.62	......	1.69	2 93	7.6	30.8
Average	59.1	10.0	65.6	65.3	6.56	387.7	3.36	198.7	586.4	5.59	[2]1.07	4.52	[3].438	1.69	2.83	7.3	32.1
Nov. 30	......	......	77.6	77.2	7.76	459.4	3.68	217.9	677.3	6.59	......	5.49	......	2.12	3.37	7.3	32.1
	......	......	78.4	78.0	7.84	464.1	4.15	245.7	709.8	6.69	......	5.59	......	2.14	3.45	7.4	31.7
	......	......	78.8	78.4	7.88	466.5	4.15	245.7	712.2	6.72	......	5.62	......	2.15	3.47	7.4	31.7
	......	......	79.0	78.6	7.90	467 7	4.21	249.2	716.9	6.83	......	5.73	......	2.16	3.57	7.6	30.8
Average	59.2	10.0	78.5	78.1	7.85	464.4	4.05	239.6	704.1	6.72	[2]1.10	5.62	[4].464	2.15	3.47	7.5	31.2

Dec. 1	......	......	79.3	78.9	7.93	470.2	4.17	247.3	717.5	6.37	......	5.29	......	2.18	3.11	6.6	35.4
	......	......	80.1	79.7	8.01	475.0	4.34	257.4	732.4	6.60	......	5.52	......	2.20	3.32	7.0	33.4
	......	......	80.6	80.2	8.06	478.0	4.45	263.9	741.9	6.67	......	5.59	......	2.22	3.37	7.1	33.0
	......	......	80.0	79.6	8.00	474.4	4.54	269.2	743.6	6.79	......	5.71	......	2.21	3.50	7.4	31.7
Average	59.3	10.0	80.0	79.6	8.00	474.4	4.38	259.5	733.9	6.61	[1]1.08	5.53	[2].466	2.21	3.32	7.0	33.4
Dec. 2	......	......	68.7	68.4	6.87	406.0	3.58	211.6	617.6	5.57	......	4.49	......	1.70	2.79	6.9	33.9
	......	......	68.7	68.4	6.87	406.0	3.78	223.4	629.4	5.70	......	4.62	......	1.70	2.92	7.2	32.5
	......	......	68.1	67.8	6.81	402.5	3.72	219.8	622.3	5.70	......	4.62	......	1.72	2.90	7.2	32.5
	......	......	67.6	67.3	6.76	399.5	3.77	222.8	622.3	5.69	......	4.61	......	1.71	2.90	7.3	32.1
Average	59.1	10.0	68.3	68.0	6.83	403.5	3.71	219.4	622.9	5.67	[1]1.08	4.59	[2].429	1.72	2.87	7.1	33.0
Dec. 3	......	......	70.7	70.3	7.07	419.9	3.79	225.1	645.0	5.88	......	4.80	......	1.85	2.95	7.0	33.4
	......	......	70.8	70.4	7.08	420.5	3.95	234.6	655.1	5.93	......	4.85	......	1.86	2.99	7.1	33.0
	......	......	70.2	69.8	7.02	417.0	3.93	233.4	650.4	5.95	......	4.87	......	1.84	3.03	7.3	32.1
	......	......	70.4	70.0	7.04	418.2	3.95	234.6	652.8	6.03	......	4.95	......	1.85	3.10	7.4	31.7
Average	59.4	10.0	70.5	70.1	7.05	418.9	3.91	231.9	650.8	5.95	[1]1.08	4.87	[2].444	1.85	3.02	7.2	32.5
Dec. 4	......	......	44.8	44.3	6.72	397.1	2.57	151.9	549.0	5.05	......	3.97	......	1.09	2.88	7.3	32.1
	......	......	44.7	44.2	6.70	395.9	2.46	145.4	541.3	5.08	......	4.00	......	1.09	2.91	7.4	31.7
	......	......	44.2	43.7	6.63	391.8	2.44	144.2	536.0	5.07	......	3.99	......	1.07	2.92	7.5	31.2
	......	......	44.0	43.5	6.60	390.0	2.37	140.1	530.1	5.07	......	3.99	......	1.07	2.92	7.5	31.2
Average	59.1	15.0	44.4	43.9	6.66	393.7	2.46	145.4	539.1	5.07	[1]1.08	3.99	[2].415	1.08	2.91	7.4	31.7
Dec. 6	......	......	41.5	41.0	6.23	368.8	2.17	128.5	497.3	4.69	......	3.61	......	1.00	2.61	7.1	33.0
	......	......	39.1	38.7	5.87	347.5	2.11	124.9	472.4	4.58	......	3.50	......	.94	2.56	7.4	31.7
	......	......	38.3	37.9	5.75	340.4	2.01	119.0	459.4	4.48	......	3.40	......	.92	2.48	7.3	32.1
	......	......	37.1	36.7	5.57	329.7	2.13	126.1	455.8	4.44	......	3.36	......	.89	2.47	7.5	31.2
Average	59.2	15.0	39.0	38.6	5.86	346.6	2.11	124.6	471.2	4.54	[1]1.08	3.46	[2].410	.92	2.54	7.3	32.1
Dec. 7	......	......	48.0	47.5	7.20	426.2	2.62	155.1	581.3	5.31	......	4.23	......	1.23	3.00	7.1	33.0
	......	......	46.9	46.4	7.04	416.8	2.43	143.9	560.7	5.21	......	4.13	......	1.21	2.92	7.0	33.4
	......	......	44.4	43.9	6.66	394.3	2.20	130.2	524.5	5.00	......	3.92	......	1.14	2.78	7.1	33.0
Average	59.2	15.0	46.4	45.9	6.97	412.4	2.42	143.1	555.5	5.17	[1]1.08	4.09	[2].439	1.20	2.89	7.0	33.4
Dec 8	......	......	57.5	56.8	8.63	504.0	......	......	......	6.11	......	5.03	......	1.45	3.58	7.1	33.0
	......	......	58.6	57.9	8.79	513.3	3.31	193.3	706.6	6.37	......	5.29	......	1.48	3.81	7.4	31.7
	......	......	58.5	57.8	8.78	512.8	3.16	184.5	697.3	6.42	......	5.34	......	1.48	3.86	7.5	31.2
	......	......	57.9	57.2	8.69	507.5	3.04	177.5	685.0	6.25	......	5.17	......	1.46	3.71	7.3	32.1
	......	......	58.4	57.7	8.76	511.6	3.30	192.7	704.3	6.43	......	5.35	......	1.48	3.87	7.6	30.8
	......	......	59.1	58.4	8.87	518.0	3.42	199.7	717.7	6.58	......	5.50	......	1.49	4.01	7.8	30.0
Average	58.4	15.0	58.3	57.6	8.75	511.2	3.25	189.5	702.2	6.36	[1]1.08	5.28	[3].438	1.47	3.81	7.5	31.2
Dec. 13	......	......	67.3	66.5	10.10	579.7	3.62	207.8	787.5	6.84	......	5.76	......	1.62	4.14	7.2	32.5
	......	......	67.2	66.4	10.08	578.6	3.99	229.0	807.6	7.03	......	5.95	......	1.62	4.33	7.5	31.2
	......	......	66.0	65.3	9.90	568.3	4.02	230.7	799.0	6.90	......	5.82	......	1.59	4.23	7.4	31.7
Average	57.4	15.0	66.8	66.1	10.03	575.5	3.88	222.5	798.0	6.92	[1]1.08	5.84	[2].425	1.61	4.23	7.3	32.1

---

[1] Average of values obtained with subject standing, in experiments without food between October 11 and December 22, 1915, inclusive. See last column of table 6, p. 46.

[2] Average for the day. See last column of table 6, p. 46, for heat-output in standing experiments, and column *i*, table 32, p. 126, for increments in the heat per horizontal kilogrammeter in horizontal walking.

[3] Average of increments per horizontal kilogrammeter obtained in periods of experiments between November 3 and December 31, 1915, inclusive, with range in speed of horizontal walking of 43.4 to 72.1 meters per minute. Experiments with hgher speeds on November 13, 15, 16, 19, and December 1 not included in average. See column *i*, table 32, p. 126.

[4] Average of increments per horizontal kilogrammeter obtained in periods of experiments on November 13, 15, 16, 19, and December 1, 1915, with range in speed of horizontal walking of 74.8 to 79.3 meters. See column *i*, table 32, p. 126.

TABLE 55.—*Increase in the heat-output of E. D. B. during grade walking in experiments without food. (Values per minute.)*—Continued.

Subject and date.	(a) Body-weight with clothing.	(b) Grade.	(c) Distance walked.	(d) Horizontal component of distance.	(e) Grade-lift of body. ($b \times c$)	(f) Work due to grade-lift. ($e \times a$)	(g) Step-lift.	(h) Work due to step-lift. ($g \times a$)	(i) Work of total lift (work of ascent). ($f + h$)	(j) Total heat during grade walking (computed).	(k) Heat due to standing.	(l) Increment over standing requirement. ($j - k$)	Heat due to horizontal component.		Increment in heat over standing and horizontal components due to grade-lift.		(q) Efficiency for grade-lift. $\frac{2.34 \times 100}{p}$
													(m) Per h. kg.m.	(n) Total. $\frac{d \times a \times m}{1,000}$	(o) Total. ($l - n$)	(p) Per kg. m. of grade-lift. $\frac{o \times 1000}{f}$	
	kg.	*p. ct.*	*meters.*	*meters.*	*meters.*	*kg. m.*	*meters.*	*kg. m.*	*kg. m.*	*cals.*	*cals.*	*cals.*	*gm.-cal.*	*cals.*	*cals.*	*gm.-cals.*	*p. ct.*
1915. Dec. 14	....	......	73.8	73.0	11.07	631.0	4.90	279.3	910.3	7.60	....	6.52	....	1.93	4.59	7.2	32.5
	....	......	74.0	73.2	11.10	632.7	4.89	278.7	911.4	7.68	....	6.60	....	1.94	4.66	7.4	31.7
	....	......	73.5	72.7	11.03	628.7	4.97	283.3	912.0	7.57	....	6.49	....	1.92	4.57	7.3	32.1
	....	......	72.8	72.0	10.92	622.4	4.95	282.1	904.5	7.50	....	6.42	....	1.90	4.52	7.2	32.5
	....	......	73.1	72.3	10.97	625.3	4.98	283.8	909.1	7.80	....	6.72	....	1.91	4.81	7.7	30.4
Average	57.0	15.0	73.4	72.6	11.02	628.0	4.94	281.4	909.5	7.62	[1]1.08	6.54	[2]0.464	1.92	.62	7.4	31.7
Dec. 15	....	......	75.0	74.2	11.25	631.1	4.89	274.3	905.4	7.70	....	6.62	....	1.93	4.69	7.4	31.7
	....	......	75.1	74.3	11.27	632.3	4.79	268.7	901.0	7.77	....	6.69	....	1.93	4.76	7.5	31.2
	....	......	74.9	74.1	11.24	630.6	4.98	279.4	910.0	7.70	....	6.62	....	1.93	4.69	7.4	31.7
	....	......	74.8	74.0	11.22	629.4	4.76	267.0	896.4	7.60	....	6.52	....	1.93	4.59	7.3	32.1
	....	......	75.3	74.4	11.30	634.0	5.01	281.1	915.1	7.80	....	6.72	....	1.94	4.78	7.5	31.2
	....	......	76.0	75.1	11.40	639.6	4.91	275.4	915.0	7.97	....	6.89	....	1.95	4.94	7.7	30.4
Average	56.1	15.0	75.2	74.4	11.28	632.8	4.89	274.3	907.2	7.76	[1]1.08	6.68	[2].464	1.94	4.74	7.5	31.2
Dec. 16	....	......	80.3	79.4	12.05	677.2	5.19	291.7	968.9	8.23	....	7.15	....	2.07	5.08	7.5	31.2
	....	......	81.0	79.2	12.15	682.8	5.20	292.2	975.0	8.19	....	7.11	....	2.07	5.04	7.4	31.7
	....	......	81.4	80.5	12.21	686.2	5.11	287.2	973.4	8.47	....	7.39	....	2.10	5.29	7.7	30.4
	....	......	80.6	79.7	12.09	679.5	5.03	282.7	962.2	8.10	....	7.02	....	2.08	4.94	7.2	32.5
	....	......	82.2	81.3	12.33	693.0	5.32	299.0	992.0	8.55	....	7.47	....	2.12	5.35	7.7	30.4
	....	......	82.0	81.1	12.30	691.3	5.16	290.0	981.3	8.61	....	7.53	....	2.11	5.42	7.8	30.0
Average	56.2	15.0	81.3	80.2	12.19	685.0	5.17	290.5	975.5	8.37	[1]1.08	7.29	[2].464	2.09	5.20	7.6	30.8
Dec. 17	....	......	54.7	53.6	10.94	616.0	3.74	210.6	826.6	6.65	....	5.57	....	1.32	4.25	6.9	33.9
	....	......	54.4	53.3	10.88	612.6	3.61	203.2	815.8	6.74	....	5.66	....	1.31	4.35	7.1	33.0
	....	......	52.0	50.9	10.40	585.5	3.65	205.5	791.0	6.45	....	5.37	....	1.25	4.12	7.0	33.4
	....	......	53.4	52.3	10.68	601.2	3.81	214.5	815.7	6.65	....	5.57	....	1.29	4.28	7.1	33.0
	....	......	53.6	52.5	10.72	603.5	3.71	208.9	812.4	6.63	....	5.55	....	1.29	4.26	7.1	33.0
	....	......	52.2	51.1	10.44	587.8	3.66	206.1	793.9	6.68	....	5.60	....	1.26	4.34	7.4	31.7
Average	56.3	20.0	53.4	52.3	10.68	601.1	3.70	208.1	809.2	6.63	[1]1.08	5.55	[3].438	1.29	4.26	7.1	33.0
Dec. 18	....	......	39.7	38.9	7.94	452.6	2.74	156.2	608.8	5.24	....	4.16	....	.97	3.19	7.1	33.0
	....	......	37.8	37.0	7.56	430.9	2.79	159.0	589.9	5.04	....	3.96	....	.92	3.04	7.1	33.0
	....	......	37.6	36.8	7.52	428.6	2.83	161.3	589.9	5.05	....	3.97	....	.92	3.05	7.1	33.0
	....	......	45.8	44.9	9.16	522.1	3.55	202.4	724.5	5.73	....	4.65	....	1.12	3.53	6.8	34.4
	....	......	45.3	44.4	9.06	516.4	3.45	196.6	713.0	5.76	....	4.68	....	1.11	3.57	6.9	33.9
	....	......	44.4	43.5	8.88	560.1	3.41	194.4	700.5	5.66	....	4.58	....	1.09	3.49	6.9	33.9
Average	57.0	20.0	41.8	40.9	8.34	476.1	3.13	178.3	654.4	5.41	[1]1.08	4.33	[3].438	1.02	3.31	7.0	33.4

Dec. 20	......	......	65.6	64.3	13.12	754.7	5.11	293.8	1,048.2	8.03	......	6.95	......	1.62	5.33	7.1	33.0
	......	......	65.8	64.5	13.16	756.7	5.11	293.8	1,050.5	8.09	......	7.01	......	1.63	5.38	7.1	33.0
	......	......	66.0	64.7	13.20	759.0	4.99	286.9	1,045.9	8.10	......	7.02	......	1.63	5.39	7.1	33.0
	......	......	66.4	65.1	13.28	763.6	4.89	281.2	1,044.8	8.09	......	7.01	......	1.64	5.37	7.0	33.4
	......	......	67.5	66.1	13.50	776.3	5.07	291.5	1,067.8	8.50	......	7.42	......	1.66	5.76	7.4	31.7
	......	......	67.1	65.7	13.42	771.7	5.02	288.6	1,060.3	8.54	......	7.46	......	1.65	5.81	7.5	31.2
Average	57.5	20.0	66.4	65.1	13.28	763.6	5.03	289.3	1,052.9	8.22	[1]1.08	7.14	[3].438	1.64	5.50	7.2	32.5
Dec. 21	......	......	69.4	68.0	13.88	793.9	4.99	285.4	1,079.3	8.48	......	7.46	......	1.70	5.76	7.3	32.1
	......	......	70.5	69.1	14.10	806.5	4.65	266.0	1,072.6	8.88	......	7.86	......	1.73	6.13	7.6	30.8
	......	......	70.9	69.5	14.18	811.1	4.78	273.4	1,084.6	8.97	......	7.95	......	1.74	6.21	7.7	30.4
Average	57.2	20.0	70.3	68.9	13.05	303.8	4.81	274.9	1,078.8	8.78	[4]1.02	7.76	[3].438	1.72	6.04	7.5	31.2
Dec. 22	......	......	69.4	68.0	13.88	788.4	5.19	294.8	1,083.2	8.44	......	7.37	......	1.69	5.68	7.2	32.5
	......	......	69.5	68.1	13.90	789.5	5.24	297.6	1,087.1	8.58	......	7.51	......	1.69	5.82	7.4	31.7
	......	......	71.2	69.8	14.24	808.8	5.20	295.4	1,104.2	8.74	......	7.67	......	1.73	5.94	7.4	31.7
Average	56.8	20.0	70.0	68.6	14.01	795.6	5.21	295.9	1,091.5	8.59	[4]1.07	7.52	[3].438	1.70	5.82	7.3	32.1
Dec. 31	......	......	79.6	78.0	15.92	926.6	3.87	225.2	1,151.8	10.94	......	9.70	......	2.20	7.50	8.1	28.9
	......	......	80.6	79.0	16.12	938.2	5.51	320.7	1,258.9	11.41	......	10.17	......	2.23	7.94	8.5	27.5
Average	58.2	20.0	80.1	78.5	16.02	932.4	4.69	273.0	1,205.4	11.18	[4]1.24	9.94	[5].485	2.22	7.72	8.3	28.2
1916 Jan. 1	......	......	79.3	77.7	15.86	923.1	5.54	322.4	1,245.5	10.65	......	9.46	......	2.19	7.27	7.9	29.6
	......	......	80.1	78.5	16.02	932.4	5.55	323.0	1,255.4	11.18	......	9.99	......	2.22	7.77	8.3	28.2
	......	......	81.6	80.0	16.32	949.8	5.63	327.7	1,277.5	11.63	......	10.44	......	2.26	8.18	8.6	27.2
Average	58.2	20.0	80.3	78.7	16.07	935.1	5.57	324.4	1,259.5	11.13	[6]1.19	9.94	[5].485	2.23	7.71	8.3	28.2
Jan. 3	......	......	43.1	41.7	10.78	635.0	3.56	209.7	844.7	7.01	......	5.80	......	1.14	4.66	7.3	32.1
	......	......	42.5	41.2	10.63	626.1	3.84	226.2	852.3	7.01	......	5.80	......	1.12	4.68	7.5	31.2
	......	......	42.3	40.9	10.58	623.2	3.85	226.8	850.0	6.97	......	5.76	......	1.10	4.66	7.5	31.2
Average	58.9	25.0	42.6	41.3	10.66	628.1	3.75	220.9	839.0	7.00	[4]1.21	5.79	[7].462	1.12	4.67	7.5	31.2
Jan. 4	......	......	59.2	57.3	14.80	860.0	5.06	294.0	1,154.0	9.42	......	8.23	......	1.54	6.69	7.8	30.0
	......	......	60.5	58.6	15.13	879.1	5.33	309.7	1,188.8	9.55	......	8.36	......	1.58	6.78	7.7	30.4
	......	......	60.4	58.5	15.10	877.3	5.35	310.8	1,188.1	9.76	......	8.57	......	1.57	7.00	8.0	29.2
	......	......	60.1	58.2	15.03	873.2	5.61	325.9	1,199.1	9.75	......	8.56	......	1.56	7.00	8.0	29.2
Average	58.1	25.0	60.1	58.2	15.02	872.4	5.34	310.1	1,182.5	9.63	[4]1.19	8.44	[7].462	1.56	6.88	7.8	30.0

---

[1] Average of values obtained with subject standing, in experiments without food between October 11 and December 22, 1915, inclusive. See last column of table 6, p. 46.

[2] Average of increments per horizontal kilogrammeter obtained in periods of experiments on November 13, 15, 16, 19, and December 1, 1915, with range in speed of horizontal walking of 74.9 to 78.9 meters. See column *i*, table 32, p. 126.

[3] Average of increments per horizontal kilogrammeter obtained in periods of experiments between November 3 and December 31, 1915, inclusive, with range in speed of horizontal walking of 43.4 to 72.1 meters. Experiments with higher speeds on November 13, 15, 16, 19, and December 1 not included in average. See column *i*, table 32, p. 126.

[4] Average for the day. See last column of table 6, p. 46.

[5] Average of increments per horizontal kilogrammeter obtained in periods of experiments on March 22, April 5 and 10, 1916, with range in speed of horizontal walking of 74.8 to 79.3 meters. See column *i*, table 32, p. 126.

[6] Average of values obtained with subject standing, in experiments between December 31, 1915, and April 15, 1916, inclusive, excluding February 12 to 23, 1916. See last column of table 6, p. 46.

[7] Average of increments per horizontal kilogrammeter obtained in periods of experiments on February 1, March 20, 29, 30, 31, and April 1, 1916, with range in speed of horizontal walking of 50.4 to 68.5 meters. See column *i*, table 32, p. 126.

TABLE 55.—*Increase in the heat-output of E. D. B. during grade walking in experiments without food.* (*Values per minute.*)—Continued.

Subject and date.	(a) Body-weight with clothing.	(b) Grade.	(c) Distance walked.	(d) Horizontal component of distance.	(e) Grade-lift of body. $(b \times c)$	(f) Work due to grade-lift. $(e \times a)$	(g) Step-lift.	(h) Work due to step-lift. $(g \times a)$	(i) Work of total lift (work of ascent). $(f + h)$	(j) Total heat during grade walking (computed).	(k) Heat due to standing.	(l) Increment over standing requirement. $(j - k)$	Heat due to horizontal component.		Increment in heat over standing and horizontal components due to grade-lift.		(q) Efficiency for grade-lift. $\frac{2.34 \times 100}{p}$
													(m) Per h. kg. m.	(n) Total. $\frac{d \times a \times m}{1,000}$	(o) Total. $(l - n)$	(p) Per kg. m. of grade-lift. $\frac{o \times 1,000}{f}$	
1916.	*kg.*	*p. ct.*	*meters.*	*meters.*	*meters.*	*kg. m.*	*meters.*	*kg. m.*	*kg. m.*	*cals.*	*cals.*	*cals.*	*gm.-cal.*	*cals.*	*cals.*	*gm.-cals.*	*p. ct.*
Jan. 5	......	......	69.5	67.3	17.37	995.3	5.74	328.9	1,324.2	11.20	......	9.98	......	1.78	8.20	8.3	28.2
	......	......	69.1	66.9	17.28	990.1	5.91	338.6	1,328.7	11.03	......	9.81	......	1.77	8.04	8.1	28.9
Average	57.3	25.0	69.3	67.1	17.33	992.7	5.83	333.8	1,326.5	11.12	[1]1.22	9.90	[2]0.462	1 78	8.12	8.2	28.5
Feb. 2	......	......	45.3	43.9	11.33	694.5	4.10	251.3	945.8	7.65	......	6.46	......	1.24	5.22	7.5	31.2
	......	......	46.6	45.1	11.65	714.1	4.49	275.2	989.3	8.21	......	7.02	......	1.28	5.74	8.0	29.2
	......	......	47.5	46.0	11.88	728.2	4.34	266.0	994.2	8.73	......	7.54	......	1.30	6.24	8.6	27.2
Average	61.3	25.0	46.5	45.0	11.62	712.3	4.31	264.2	976.4	8.19	[3]1.19	7.00	[2].462	1.27	5.73	8.0	29.2
Feb. 3	......	......	51.6	50.0	12.90	776.6	4.46	268.5	1,045.1	8.52	......	7.33	......	1.39	5.94	7.6	30.8
	......	......	53.6	51.9	13.40	806.7	3.67	220.9	1,027.6	9.08	......	7.89	......	1.44	6.45	8.0	29.2
	......	......	52.7	51.0	13.18	793.4	4.05	243.8	1,037.2	8.88	......	7.69	......	1.42	6.27	7.9	29.6
Average	60.2	25.0	52.6	51.0	13.16	792.2	4.06	244.4	1,036.6	8.82	[3]1.19	7.63	[2].462	1.42	6.21	7.8	30.0
Feb. 4	......	......	60.8	58.9	15.20	910.5	1.31	78.5	989.0	9.67	......	8.48	......	1.63	6.85	7.5	31.2
	......	......	62.7	60.7	15.68	939.2	1.07	64.1	1,003.3	10.54	......	9.35	......	1.68	7.67	8.2	28.5
	......	......	63.2	61.2	15.80	946.4	5.81	348.0	1,294.4	10.68	......	9 49	......	1.69	7.80	8.2	28.5
Average	59.9	25.0	62.2	60.3	15.56	932.0	2.73	163.5	1,095.6	10.29	[3]1.19	9.10	[2] 462	1.67	7.43	8.0	29.2
Feb. 5	......	......	68.0	65.8	17.00	1,020.0	5.82	349.2	1,369.2	10.78	......	9.59	......	1.82	7.77	7.6	30.8
	......	......	72.1	69.8	18.03	1,082.0	6.30	378.0	1,460.0	11.80	......	10.61	......	1.93	8.68	8.0	29.2
	......	......	73.0	70.7	18.25	1,095.0	6.05	363.0	1,458.0	11.77	......	10.58	......	1.96	8.62	7.9	29.6
Average	60.0	25.0	71.0	68.8	17.66	1,065.7	6.06	363.4	1,429.1	11.43	[3]1.19	10.24	[2].462	1.91	8.33	7.8	30.0
Feb. 7	......	......	74.7	72.3	18.68	1,128.0	6.99	422.2	1,550.2	12.49	......	11.30	......	2.12	9.18	8.2	28.5
	......	......	76.5	74.1	19.13	1,155.0	7.22	436.1	1,591.1	12.89	......	11.70	......	2.17	9.53	8.3	28.2
	......	......	76.4	74.0	19.10	1,154.0	6.65	401.6	1,555.6	12.41	......	11.22	......	2.17	9.05	7.8	30.0
Average	60.4	25.0	75.9	73.5	18.97	1,145.7	6.95	420.0	1,565.6	12.61	[3]1.19	11.42	[4].485	2.15	9.27	8.1	28.9

Feb. 8	......	......	49.3	47.0	14.79	888.9	4.84	290.3	1,179.8	8.92	......	7.73	......	1.31	6.42	7.2	32.5
	......	......	49.6	47.3	14.88	894.3	5.03	302.3	1,196.6	9.17	......	7.98	......	1.31	6.67	7.5	31.2
	......	......	42.5	40.5	12.75	766.3	4.10	246.4	1,012.7	7.95	......	6.76	......	1.13	5.63	7.3	32.1
	......	......	42.4	40.4	12.72	764.5	4.42	265.6	1,030.1	8.04	......	6.85	......	1.12	5.73	7.5	31.2
Average	60.1	30.0	46.0	43.8	13.79	828.5	4.60	276.3	1,104.8	8.53	[3]1.19	7.34	[2].462	1.22	6.12	7.4	31.7
Feb. 9	......	......	48.8	46.6	14.64	878.4	5.13	307.8	1,186.2	9.05	......	7.86	......	1.29	6.57	7.5	31.2
	......	......	50.2	47.9	15.06	903.6	5.38	322.8	1,226.4	9.66	......	8.47	......	1.33	7.14	7.9	29.6
	......	......	57.3	54.7	17.19	1,031.0	5.75	345.0	1,376.0	10.82	......	9.63	......	1.52	8.11	7.9	29.6
	......	......	57.9	55.2	17.37	1,042.0	5.58	334.8	1,376.8	10.80	......	9.61	......	1.53	8.08	7.7	30.4
Average	60.0	30.0	53.6	51.1	16.07	963.8	5.46	327.6	1,291.4	10.08	[3]1.19	8.89	[2].462	1.42	7.47	7.7	30.4
Feb. 10	......	......	60.5	57.7	18.15	1,089.0	5.69	341.4	1,430.4	10.93	......	9.74	......	1.60	8.14	7.5	31.2
	......	......	62.6	59.7	18.78	1,127.0	6.27	376.2	1,503.2	11.66	......	10.47	......	1.66	8.81	7.8	30.0
Average	60.0	30.0	61.6	58.7	18.47	1,108.0	5.98	358.8	1,466.8	11.29	[3]1.19	10.10	[2].462	1.63	8.47	7.7	30.4
Feb. 11	......	......	69.4	66.2	20.82	1,249.2	7.56	453.6	1,702.8	13.04	......	11.85	......	1.84	10.01	8.0	29.2
	......	......	69.1	65.9	20.73	1,243.8	6.91	414.6	1,658.4	12.95	......	11.76	......	1.82	9.94	8.0	29.2
	......	......	69.9	66.7	20.97	1,258.2	6.84	410.4	1,668.6	13.07	......	11.88	......	1.85	10.03	8.0	29.2
Average	60.0	30.0	69.5	66.3	20.83	1,250.4	7.10	426.2	1,676.6	13.00	[3]1.19	11.81	[2].462	1.84	9.97	8.0	29.2
Feb. 12	......	......	68.3	65.2	20.49	1,239.6	6.61	399.9	1,639.5	12.21	......	11.04	......	1.82	9.22	7.4	31.7
	......	......	74.6	71.2	22.38	1,353.9	7.07	427.7	1,781.6	13.81	......	12.64	......	1.99	10.65	7.9	29.6
Average	60.5	30.0	71.5	68.2	21.44	1,296.8	6.84	413.8	1,710.6	13.03	[3]1.17	11.86	[2].462	1.91	9.95	7.7	30.4
Feb. 14	......	......	67.8	64.7	20.34	1,216.3	6.82	407.8	1,624.1	12.16	......	11.00	......	1.79	9.21	7.6	30.8
	......	......	68.8	65.6	20.64	1,234.3	7.02	419.8	1,654.1	12.48	......	11.32	......	1.81	9.51	7.7	30.4
Average	59.8	30.0	68.3	65.2	20.49	1,225.3	6.92	413.8	1,639.1	12.31	[1]1.16	11.15	[2].462	1.80	9.35	7.7	30.4
Feb. 15	......	......	43.1	40.4	15.09	897.9	4.31	256.4	1,154.3	9.44	......	8.19	......	1.11	7.08	7.9	29.6
	......	......	45.7	42.8	16.00	952.0	4.85	288.6	1,240.6	9.96	......	8.71	......	1.18	7.53	7.9	29.6
	......	......	46.2	43.3	16.17	962.1	5.09	302.8	1,264.9	9.98	......	8.73	......	1.19	7.54	7.8	30.0
Average	59.5	35.0	45.0	42.2	15.75	937.3	4.75	282.6	1,219.9	9.78	[1]1.25	8.53	[2].462	1.16	7.37	7.9	29.6
Feb. 16	......	......	57.7	54.1	20.20	1,205.9	6.15	367.3	1,573.2	12.64	......	11.42	......	1.49	9.93	8.2	28.5
	......	......	58.5	54.8	20.48	1,222.6	6.28	374.9	1,597.5	12.49	......	11.27	......	1.51	9.76	8.0	29.2
	......	......	56.6	53.0	19.81	1,182.6	5.89	351.6	1,534.2	11.81	......	10.59	......	1.46	9.13	7.7	30.4
Average	59.7	35.0	57.6	54.0	20.16	1,203.7	6.11	364.6	1,568.3	12.32	[1]1.22	11.10	[2].462	1.49	9.61	8.0	29.2
Feb. 17	......	......	62.3	58.4	21.81	1,304.2	6.72	401.9	1,706.1	13.51	......	12.23	......	1.61	10.62	8.2	28.5
	......	......	62.5	58.5	21.88	1,308.4	6.80	406.6	1,715.0	13.46	......	12.18	......	1.61	10.57	8.1	28.9
Average	59.8	35.0	62.4	58.5	21.85	1,306.3	6.76	404.3	1,710.6	13.48	[1]1.28	12.20	[2].462	1.61	10.59	8.1	28.9
Feb. 18	......	......	46.1	42.3	18.44	1,106.4	5.36	321.6	1,428.0	10.93	......	9.67	......	1.17	8.50	7.7	30.4
	......	......	50.6	46.4	20.24	1,214.4	5.57	334.2	1,548.6	11.75	......	10.49	......	1.29	9.20	7.6	30.8
	......	......	51.8	47.5	20.72	1,243.2	6.00	360.0	1,603.2	12.46	......	11.20	......	1.32	9.88	7.9	29.6
Average	60.0	40.0	49.5	45.4	19.80	1,188.0	5.64	338.6	1,526.6	11.70	[1]1.26	10.44	[2].462	1.26	9.18	7.7	30.4

---

[1] Average for the day. See last column of table 6, p. 46.

[2] Average of increments per horizontal kilogrammeter obtained in periods of experiments on February 1, March 20, 29, 30, 31, and April 1, 1916, with range in speed of horizontal walking of 50.4 to 68.5 meters. See table 32, p. 126.

[3] Average of values obtained with subject standing, in experiments between December 31, 1915, and April 15, 1916, inclusive, excluding February 12 to 23, 1916. See last column of table 6, p. 46.

[4] Average of increments per horizontal kilogrammeter obtained in periods of experiments on March 22, April 5 and 10, 1916, with range in speed of horizontal walking of 74.8 to 79.3 meters. See table 32, p. 126.

TABLE 55.—*Increase in the heat-output of E. D. B. during grade walking in experiments without food. (Values per minute.)*—Continued.

Subject and date.	(a) Body-weight with clothing.	(b) Grade.	(c) Distance walked.	(d) Horizontal component of distance.	(e) Grade-lift of body. (b × c)	(f) Work due to grade-lift. (e × a)	(g) Step-lift.	(h) Work due to step-lift. (g × a)	(i) Work of total lift (work of ascent). (f + h)	(j) Total heat during grade walking (computed).	(k) Heat due to standing.	(l) Increment over standing requirement. (j—k)	Heat due to horizontal component.		Increment in heat over standing and horizontal components due to grade-lift.		(q) Efficiency for grade-lift. $\frac{2.34 \times 100}{p}$
													(m) Per h.kg.m.	(n) Total. $\frac{d \times a \times m}{1,000}$	(o) Total. (l − n)	(p) Per kg. m. of grade-lift. $\frac{o \times 1,000}{f}$	
1916.	*kg.*	*p. ct.*	*meters.*	*meters.*	*meters.*	*kg. m.*	*meters.*	*kg. m.*	*kg. m.*	*cals.*	*cals.*	*cals.*	*gm.-cal.*	*cals.*	*cals.*	*gm.-cals.*	*p. ct.*
Feb. 19	......	.....	53.7	49.2	21.48	1,295.2	5.27	317.8	1,613.0	12.76	....	11.58	....	1.37	10.21	7.9	29.6
	......	.....	54.3	49.8	21.72	1,309.7	6.31	380.5	1,690.2	13.22	....	12.04	....	1.39	10.65	8.1	28.9
	......	.....	54.0	49.5	21.60	1,302.4	6.25	376.9	1,679.3	12.80	....	11.62	....	1.38	10.24	7.9	29.6
Average	60.3	40.0	54.0	49.5	21.60	1,302.4	5.94	358.4	1,660.8	12.92	[1]1.18	11.74	[2]0.462	1.38	10.36	7.9	29.6
Feb. 21	......	.....	57.2	52.4	22.88	1,386.5	6.03	365.4	1,751.9	13.82	....	12.52	....	1.47	11.05	8.0	29.2
	......	.....	57.2	52.4	22.88	1,386.5	6.60	399.9	1,786.4	13.85	....	12.55	....	1.47	11.08	8.0	29.2
	......	.....	57.0	52.2	22.80	1,381.7	6.64	402.4	1,784.1	13.70	....	12.40	....	1.46	10.94	7.9	29.6
Average	60.6	40.0	57.1	52.3	22.85	1,384.9	6.42	389.2	1,774.1	13.80	[1]1.30	12.50	[2].462	1.46	11.04	8.0	29.2
Feb. 22	......	.....	64.9	59.5	25.96	1,562.8	6.72	404.5	1,967.3	15.55	....	14.35	....	1.65	12.70	8.1	28.9
	......	.....	65.4	59.9	26.16	1,574.8	7.49	450.9	2,025.7	15.79	....	14.59	....	1.66	12.93	8.2	28.5
Average	60.2	40.0	65.2	59.7	26.06	1,568.8	7.11	427.7	1,996.5	15.65	[1]1.20	14.45	[2].462	1.66	12.79	8.2	28.5
Feb. 23	......	.....	40.6	36.3	18.27	1,101.7	5.31	320.2	1,421.9	12.01	....	10.82	....	1.01	9.81	8.9	26.3
	......	.....	41.8	37.3	18.81	1,134.2	5.31	320.2	1,454.4	11.85	....	10.66	....	1.02	9.64	8.5	27.5
	......	.....	44.1	39.4	19.85	1,197.0	5.77	347.9	1,544.9	12.59	....	11.40	....	1.07	10.33	8.7	27.0
Average	60.3	45.0	42.2	37.7	18.98	1,144.3	5.46	329.4	1,473.7	12.16	[1]1.19	10.97	[2].462	1.05	9.92	8.7	27.0
Feb. 24	......	.....	42.8	38.2	19.26	1,159.5	5.81	349.8	1,509.3	12.10	....	10.86	....	1.06	9.80	8.5	27.5
	......	.....	42.1	37.6	18.95	1,140.8	5.46	328.7	1,469.5	11.63	....	10.39	....	1.05	9.34	8.2	28.5
Average	60.2	45.0	42.5	37.9	19.11	1,150.2	5.64	339.3	1,489.4	11.85	[1]1.24	10.61	[2].462	1.05	9.56	8.3	28.2
Feb. 25	......	.....	60.7	57.9	18.21	1,107.2	5.86	356.3	1,463.5	11.09	....	9.89	....	1.63	8.26	7.5	31.2
	......	.....	60.9	58.1	18.27	1,110.8	6.10	370.9	1,481.7	11.45	....	10.25	....	1.63	8.62	7.8	30.0
Average	60.8	30.0	60.8	58.0	18.24	1,109.0	5.98	363.6	1,472.6	11.26	[1]1.20	10.06	[2].462	1.63	8.43	7.6	30.8

Feb. 26	...	...	68.6	65.4	20.58	1,255.4	6.52	397.7	1,653.1	12.41	...	11.19	...	1.84	9.35	7.5	31.2
	...	...	70.1	66.9	21.03	1,282.8	6 39	389.8	1,672.6	13.23	...	12.01	...	1.89	10.12	7.9	29.6
Average	61.0	30.0	69.4	66.2	20.81	1,269.1	6.46	393 8	1,662.9	12.83	[1]1.22	11.61	[2].462	1.87	9.74	7.7	30.4
Feb. 28	...	...	66.7	63.6	20.01	1,230.6	4.39	270.0	1,500.6	12.15	...	10.96	...	1.81	9.15	7.4	31.7
	...	...	67.1	64.0	20.13	1,238.0	4.79	294.6	1,532.6	12.83	...	11.64	...	1.82	9.82	8.0	29.2
Average	61.5	30.0	66.9	63.8	20.07	1,234.3	4.59	282.3	1,516.6	12.50	[1]1.19	11.31	[2].462	1.81	9.50	7.7	30.4
Feb. 29	...	...	68.4	65.2	20.52	1,241.5	6.74	407.8	1,649.3	12.05	...	10.95	...	1.82	9.13	7.3	32.1
	...	...	68.5	65.3	20.55	1,243.3	6.95	420.5	1,663.8	12.57	...	11.47	...	1.82	9.65	7.8	30.0
Average	60.5	30.0	68.5	65.3	20.54	1,242.4	6.85	414.2	1,656.6	12.33	[1]1.10	11.23	[2].462	1.82	9.41	7.6	30.8
Mar. 4	...	...	49.1	46.8	14.73	898.5	...	...	...	8.73	...	7.54	...	1.32	6.22	6.9	33.9
	...	...	48.6	46.4	14.58	889.4	...	...	...	8.98	...	7.79	...	1.31	6.48	7.3	32.1
	...	...	47.2	45.0	14.16	863.8	...	...	...	8.60	...	7.41	...	1.27	6.14	7.1	33.0
	...	...	49.1	46.8	14.73	898.5	...	...	...	9.31	...	8.12	...	1.32	6.80	7.6	30.8
Average	61 0	30.0	48.5	46.3	14.55	887.6	...	...	...	8.89	[3]1.19	7.70	[2].462	1.30	6.40	7.2	32.5
Mar. 6	...	...	51.1	48.7	15.33	933.6	...	...	...	9.52	...	8.33	...	1.37	6.96	7.5	31.2
	...	...	52.2	49.8	15.66	953.7	...	...	...	9.89	...	8.70	...	1.39	7.31	7.7	30.4
	...	...	52.5	50.1	15.75	959.2	...	...	...	10.02	...	8.83	...	1.41	7.42	7.7	30.4
	...	...	53.0	50.6	15.90	968.3	...	...	...	9.90	...	8.71	...	1.43	7.28	7.5	31.2
Average	60.9	30.0	52.2	49.8	15.66	953.7	...	...	...	9.82	[3]1.19	8.63	[2].462	1.39	7.24	7.6	30.8
Mar. 7	...	...	51.0	48.7	15.30	925.7	...	...	...	9.47	...	8.28	...	1.36	6.92	7.5	31.2
	...	...	51.1	48.7	15.33	927.5	...	...	...	9.49	...	8.30	...	1.36	6.94	7.5	31.2
Average	60.5	30.0	51.1	48.7	15.32	926.6	...	...	...	9.48	[3]1.19	8.29	[2].462	1.36	6.93	7.5	31.2
Mar. 8	...	...	51.2	48.8	15.36	924.7	...	...	...	9.38	...	8.19	...	1.36	6.83	7.4	31.7
	...	...	51.2	48.8	15.36	924.7	...	...	...	9.54	...	8.35	...	1.36	6.99	7.6	30.8
	...	...	51.3	48.9	15.39	926.5	...	...	...	9.70	...	8.51	...	1.36	7.15	7.7	30.4
	...	...	52.3	49.9	15.69	944.5	...	...	...	10.08	...	8.89	...	1.39	7.50	7.9	29.6
	...	...	51.5	49.1	15.45	930.1	...	...	...	9.85	...	8.66	...	1.37	7.29	7.8	30.0
	...	...	51.7	49.3	15.51	933.7	...	...	...	9.91	...	8.72	...	1.37	7.35	7.9	29.6
Average	60.2	30.0	51.5	49.1	15.46	930.7	...	...	...	9.76	[3]1.19	8.57	[2].462	1.37	7.20	7.7	30.4
Mar. 23	...	...	62.5	62.2	6.25	381.3	...	...	...	5.45	...	4.25	...	1.75	2.50	6.6	35.4
	...	...	61.9	61.6	6.19	377.6	...	...	...	5.34	...	4.14	...	1.74	2.40	6.4	36.6
Average	61.0	10.0	62.2	61.9	6.22	379.5	...	...	...	5.39	[1]1.20	4.19	[2].462	1.75	2.44	6.4	36.6
Mar. 24	...	...	57.1	56.9	5.08	310.4	...	...	...	4.91	...	3.68	...	1.61	2.07	6.7	35.0
	...	...	56.7	56.5	5.05	308.6	...	...	...	4.84	...	3.61	...	1.60	2.01	6.5	36.0
Average	61.1	8.9	56.9	56.7	5.07	309.5	...	...	...	4.88	[1]1.23	3.65	[2].462	1.60	2.05	6.6	35.4

---

[1] Average for the day. See last column of table 6, p. 46.

[2] Average of increments per horizontal kilogrammeter obtained in periods of experiments on February 1, March 20, 29, 30, 31, and April 1, 1916, with range in speed of horizontal walking of 50.4 to 68.5 meters. See table 32, p. 126.

[3] Average of values obtained with subject standing, in experiments between December 31, 1915, and April 15, 1916, inclusive, excluding February 12 to 23, 1916. See last column of table 6, p. 46.

TABLE 55.—*Increase in the heat-output of E. D. B. during grade walking in experiments without food.* (*Values per minute.*)—Continued.

Subject and date.	(*a*) Body-weight with clothing.	(*b*) Grade.	(*c*) Distance walked.	(*d*) Horizontal component of distance.	(*e*) Grade-lift of body. (*b* × *c*)	(*f*) Work due to grade-lift. (*e* × *a*)	(*g*) Step-lift.	(*h*) Work due to step-lift. (*g* × *a*)	(*i*) Work of total lift (work of ascent). (*f* + *h*)	(*j*) Total heat during grade walking (computed).	(*k*) Heat due to standing.	(*l*) Increment over standing requirement. (*j* − *k*)	Heat due to horizontal component.		Increment in heat over standing and horizontal components due to grade-lift.		(*g*) Efficiency for grade-lift. $\frac{2.34 \times 100}{p}$
													(*m*) Per h.kg.m.	(*n*) Total. $\frac{d \times a \times m}{1,000}$	(*o*) Total. (*l*−*n*)	(*p*) Per kg. m. of grade-lift $\frac{o \times 1,000}{f}$	
1916.	*kg.*	*p. ct.*	*meters.*	*meters.*	*meters.*	*kg. m.*	*meters.*	*kg. m.*	*kg. m.*	*cals.*	*cals.*	*cals.*	*gm.-cal.*	*cals.*	*cals.*	*gm.-cals.*	*p. ct.*
Apr. 6	......	......	46.3	46.1	4.63	279.7	......	......	......	4.42	......	3.25	......	1.29	1.96	7.0	33.4
	......	......	47.4	47.2	4.74	286.3	......	......	......	4.42	......	3.25	......	1.32	1.93	6.8	34.4
	......	......	47.3	47.1	4.73	285.7	......	......	......	4.41	......	3.24	......	1.32	1.92	6.7	35.0
Average	60.4	10.0	47.0	46.8	4.70	283.9	......	......	......	4.42	[1]1.17	3.25	[2]0.462	1.31	1.94	6.8	34.4
Apr. 7	......	......	45.6	45.4	4.56	275.9	......	......	......	4.38	......	3.22	......	1.27	1.95	6.8	34.4
	......	......	46.5	46.3	4.65	281.3	......	......	......	4.41	......	3.25	......	1.29	1.96	7.0	33.4
	......	......	47.2	47.0	4.72	285.6	......	......	......	4.43	......	3.27	......	1.31	1.96	6.9	33.9
Average	60.5	10.0	46.4	46.2	4.64	280.9	......	......	......	4.41	[1]1.16	3.25	[2].462	1.29	1.96	7.0	33.4
Apr. 8	......	......	35.2	35.0	3.52	218.9	......	......	......	3.88	......	2.69	......	1.01	1.68	7.7	30.4
	......	......	36.2	36.0	3.62	225.2	......	......	......	3.83	......	2.64	......	1.03	1.61	7.2	32.5
	......	......	36.0	35.8	3.60	223.9	......	......	......	3.82	......	2.63	......	1.03	1.60	7.2	32.5
Average	62.2	10.0	35.8	35.6	3.58	222.7	......	......	......	3.84	[1]1.19	2.65	[2].462	1.02	1.63	7.3	32.1
Apr. 14	......	......	40.5	40.4	2.03	126.1	......	......	......	3.23	......	2.07	......	1.16	.91	7.2	32.5
	......	......	40.8	40.7	2.04	126.7	......	......	......	3.14	......	1.98	......	1.17	.81	6.4	36.6
	......	......	39.8	39.8	1.99	123.6	......	......	......	3.04	......	1.88	......	1.14	.74	6.0	39.0
Average	62.1	5.0	40.4	40.3	2.02	125.5	......	......	......	3.14	[1]1.16	1.98	[2].462	1.16	.82	6.5	36.0
Apr. 15	......	......	39.6	39.6	.95	58.8	......	......	......	2.66	......	1.50	......	1.13	.37	6.3	37.2
	......	......	40.1	40.1	.96	59.4	......	......	......	2.58	......	1.42	......	1.15	.27	4.6	50.9
	......	......	39.5	39.5	.95	58.8	......	......	......	2.54	......	1.38	......	1.13	.25	4.3	54.4
Average	61.9	2.4	39.7	39.7	.95	59.0	......	......	......	2.59	[1]1.16	1.43	[2].462	1.14	.29	4.9	47.8

[1] Average for the day. See last column of table 6, p. 46.

[2] Average of increments per horizontal kilogrammeter obtained in periods of experiments on February 1, March 20, 29, 30, 31, and April 1, 1916, with range in speed of horizontal walking of 50.4 to 68.5 meters. See table 32, p. 126.

TABLE 56.—*Metabolism during grade walking in experiments without food, grouped according to grade and speed of walking. (Average values per minute.)*

Subject, grade, and speed.	No. of periods.	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	Heat-output (computed).			(o)
		Dis-tance walked.	No. of steps.	Work due to grade-lift.	Respi-ration-rate.	Pul-monary venti-lation (re-duced).	Pulse-rate.	Body-tem-pera-ture.	Blood-pres-sure.	Carbon dioxide.	Oxy-gen.	Res-pira-tory quo-tient.	(l) Total.	Increment above standing requirement and horizontal component due to grade-lift.		Efficiency for grade-lift. $\frac{2.34 \times 100}{n}$
														(m) Total.	(n) Per kg. m. of grade-lift.	
A. J. O.																
4 p. ct.:		*meters.*		*kg. m.*		*liters.*		*C.*	*mm.*	*c. c.*	*c. c.*		*cals.*	*cals.*	*gm. cals.*	*p. ct.*
60 to 65 meters......	[1]1	61.1	94.4	162.8	24.5	17.6	....	....	....	749	871	0.86	4.25	0.90	5.5	42.5
65 to 70 meters......	[1]1	68.1	102.6	181.3	25.2	18.0	....	....	....	822	955	.86	4.66	1.07	5.9	39.7
H. R. R.																
10 p. ct.:																
60 to 65 meters......	7	62.8	100.2	461.9	24.9	27.6	[2]140	....	....	1,283	1,555	.83	7.51	3.46	7.5	31.2
65 to 70 meters......	4	66.6	105.3	517.1	27.3	30.4	[3]147	....	....	1,432	1,704	.84	8.26	3.97	7.7	30.5
70 to 75 meters......	6	72.8	108.2	550.1	26.9	31.6	148	....	....	1,506	1,766	.85	8.60	4.08	7.4	31.8
75 to 80 meters......	6	76.5	111.8	580.3	24.6	32.0	....	....	....	1,559	1,836	.85	9.93	4.31	7.4	31.6
15 p. ct.:																
65 to 70 meters......	4	66.2	106.6	716.8	27.7	37.6	150	....	....	1,762	2,040	.86	9.99	5.80	8.1	29.0
T. H. H.																
10 p. ct.:																
55 to 60 meters......	10	57.4	100.9	332.5	18.5	17.5	[4]128	....	....	967	1,165	.83	5.64	2.75	8.0	29.3
60 to 65 meters......	18	62.6	100.5	363.1	17.9	17.9	[5]121	....	....	1,027	1,211	.85	5.89	2.71	7.5	31.3
65 to 70 meters......	10	67.0	103.0	387.8	19.1	18.9	[6]111	....	....	1,054	1,281	.82	6.19	2.92	7.5	31.2
W. K.																
3.6 and 3.9 p. ct.:																
65 to 70 meters......	9	68.7	115.7	132.4	24.0	14.5	....	....	....	672	785	.86	3.82	.80	6.0	39.6
70 to 75 meters......	3	70.2	117.7	142.9	26.3	15.1	....	....	....	665	806	.83	3.90	1.00	7.0	33.6
9.2 p. ct.:																
60 to 65 meters......	4	64.1	108.4	297.8	25.3	20.3	115	....	....	878	1,020	.86	4.94	2.23	7.5	31.6
10 p. ct.:																
55 to 60 meters......	21	58.5	103.4	308.3	24.8	18.6	119	....	....	827	1,019	.81	4.91	2.39	7.8	30.3
60 to 65 meters......	13	63.6	107.2	337.1	26.1	19.7	125	....	....	886	1,061	.84	5.14	2.45	7.3	32.3
65 to 70 meters......	9	68.3	110.0	361.6	27.1	19.2	125	....	....	913	1,162	.79	5.53	2.74	7.6	31.2
70 to 75 meters......	17	71.4	111.7	380.1	28.4	22.3	114	....	....	962	1,232	.78	5.87	2.99	7.9	29.8
75 to 80 meters......	35	77.3	116.5	413.8	28.6	22.9	124	....	....	1,067	1,288	.83	6.23	3.20	7.7	30.4
80 to 85 meters......	4	80.6	119.8	431.3	29.2	24.0	128	....	....	1,116	1,384	.81	6.62	3.51	8.2	28.7
13 p. ct.:																
55 to 60 meters......	12	58.1	102.5	382.1	25.5	20.1	....	....	....	921	1,121	.82	5.41	2.87	7.5	31.2

[1] The two periods were on the same day. [2] 4 periods. [3] 1 period. [4] Average of 9 periods. [5] Average of 15 periods. [6] Average of 4 periods.

TABLE 56.—*Metabolism during grade walking in experiments without food, grouped according to grade and speed of walking. (Average values per minute.)*—Continued.

		(*a*)	(*b*)	(*c*)	(*d*)	(*e*)	(*f*)	(*g*)	(*h*)	(*i*)	(*j*)	(*k*)	Heat-output (computed).			(*o*)
													(*l*)	Increment above standing requirement and horizontal component due to grade-lift.		
Subject, grade, and speed.	No. of periods.	Distance walked.	No. of steps.	Work due to grade-lift.	Respiration-rate.	Pulmonary ventilation (reduced).	Pulse-rate.	Body-temperature.	Blood-pressure.	Carbon dioxide.	Oxygen.	Respiratory quotient.	Total.	(*m*) Total.	(*n*) Per kg. m. of grade-lift.	Efficiency for grade-lift. $\frac{2.34 \times 100}{n}$
W. K. (cont.)																
15 p. ct.:		*meters.*		*kg. m.*		*liters.*		°*C.*	*mm.*	*c. c.*	*c. c.*		*cals.*	*cals.*	*gm. cals.*	*p. ct.*
50 to 55 meters......	2	53.8	97.3	411.6	24.0	21.3	......	......	......	993	1,167	0.85	5.67	3.24	7.9	29.6
55 to 60 meters......	20	57.4	105.9	444.3	27.5	23.2	121	......	......	1,078	1,283	.84	6.20	3.68	8.3	28.4
60 to 65 meters......	5	60.2	109.0	469.6	27.7	25.9	118	......	......	1,144	1,340	.85	6.52	3.92	8.4	28.0
65 to 70 meters......	12	66.4	114.6	517.3	28.7	26.9	137	......	......	1,288	1,467	.90	7.16	4.41	8.6	27.3
75 to 80 meters......	11	79.0	120.7	622.3	30.3	31.0	139	......	......	1,542	1,716	.90	8.45	5.37	8.6	27.2
80 to 85 meters......	10	80.5	121.8	633.0	31.8	32.2	151	......	......	1,575	1,763	.89	8.68	5.57	8.8	26.7
20 p. ct.:																
45 to 50 meters......	8	47.2	99.7	484.0	28.0	24.8	131	......	......	1,153	1,331	.87	6.50	4.23	8.8	26.6
50 to 55 meters......	4	50.3	103.8	514.3	29.8	27.3	140	......	......	1,235	1,437	.86	7.01	4.67	9.2	25.6
55 to 60 meters......	6	57.2	112.0	569.5	30.7	29.1	145	......	......	1,320	1,578	.84	7.65	5.18	9.1	25.7
60 to 65 meters......	6	63.4	117.3	632.9	33.7	35.0	156	......	......	1,498	1,734	.86	8.46	5.83	9.2	25.4
65 to 70 meters......	2	68.7	122.2	689.3	35.7	41.0	165	......	......	1,635	1,865	.88	9.14	6.37	9.3	25.3
70 to 75 meters......	9	73.9	122.1	742.9	35.9	42.2	160	......	......	1,756	1,977	.89	9.71	6.81	9.2	25.5
75 to 80 meters......	3	79.5	125.5	800.1	40.0	47.5	167	......	......	1,908	2,039	.94	10.17	7.21	9.0	25.9
25 p. ct.:																
50 to 55 meters......	7	52.6	108.9	662.5	33.7	34.2	145	......	......	1,442	1,703	.85	8.28	5.92	8.9	26.2
55 to 60 meters......	5	57.6	113.8	725.9	34.1	39.2	151	......	......	1,618	1,837	.88	9.01	6.54	9.0	26.1
65 to 70 meters......	4	66.9	120.4	842.3	38.1	50.0	166	......	......	1,917	2,103	.91	10.39	7.68	9.1	25.6
70 to 75 meters......	2	71.5	123.0	891.2	40.0	56.3	176	......	......	2,152	2,094	1.03	10.57	8.06	9.1	25.9
E. D. B.																
2.4 p. ct.:																
35 to 40 meters......	3	39.7	......	59.0	21.5	17.0	84	37.21	128	462	530	.87	2.59	.29	4.9	47.8
5 p. ct.:																
35 to 40 meters......	5	38.8	74.7	115.2	19.4	13.9	......	37.30	129	502	603	.83	2 92	.70	6.1	38.7
40 to 45 meters......	14	41.7	77.7	123.5	20.2	14.0	84	37.24	128	518	624	.83	3.02	.78	6.3	37.1
45 to 50 meters......	13	48.3	80.6	142.0	20.0	14.3	87	......	......	552	643	.86	3.13	.78	5.5	42.9
50 to 55 meters......	9	53.4	84.4	157.6	21.1	14.8	95	......	......	572	669	.86	3.26	.80	5.1	46.4
55 to 60 meters......	3	56.5	86.9	166.2	22.1	15.6	86	......	......	582	688	.85	3.34	.82	4.9	47.7
65 to 70 meters......	8	65.7	95.0	193.5	23.1	17.1	100	......	......	662	780	.85	3.79	.97	5.1	46.5
70 to 75 meters......	7	73.7	99.9	216.8	24.1	18.6	101	......	......	733	860	.85	4.18	1.12	5.1	45.8
75 to 80 meters......	5	75.1	101.9	220.8	24.7	18.7	107	......	......	748	870	.86	4.24	1.12	5.0	46.7
8.9 p. ct.:																
55 to 60 meters......	2	56.9	......	309.5	23.0	20.6	99	37.80	127	855	1,003	.85	4.88	2.04	6.6	35.5

10 p. ct.:																
35 to 40 meters......	3	35.8	....	222.7	20.5	17.4	93	37.07	139	687	784	.88	3.84	1.63	7.4	31.8
40 to 45 meters......	4	41.8	77.7	250.5	21.2	17.0	....	....	....	675	806	.84	3.90	1.71	6.8	34.4
45 to 50 meters......	10	47.2	81.1	285.4	22.6	19.4	101	37.22	128	758	898	.84	4.36	1.94	6.8	34.4
55 to 60 meters......	8	57.3	86.7	337.7	23.3	21.3	110	....	....	852	1,000	.85	4.86	2.40	7.1	32.9
60 to 65 meters......	2	62.2	....	379.5	23.9	22.7	103	37.58	118	946	1,108	.86	5.40	2.45	6.5	36.0
65 to 70 meters......	17	66.5	95.1	394.0	23.8	22.9	119	....	....	1,014	1,137	.89	5.59	2.81	7.1	32.8
70 to 75 meters......	4	70.5	97.5	418.9	25.4	25.1	118	....	....	1,074	1,212	.89	5.95	3.02	7.2	32.6
75 to 80 meters......	5	78.6	102.1	465.6	25.7	27.5	123	....	....	1,192	1,356	.88	6.64	3.39	7.3	32.3
80 to 85 meters......	3	80.2	104.5	475.8	26.5	28.8	....	....	....	1,201	1,367	.88	6.69	3.40	7.2	32.7
15 p. ct.:																
35 to 40 meters......	3	38.2	75.6	339.2	23.2	20.5	108	....	....	819	914	.90	4.50	2.50	7.4	31.7
40 to 45 meters......	5	43.8	78.2	388.7	23.5	21.7	101	....	....	899	1,017	.88	4.99	2.85	7.4	31.8
45 to 50 meters......	3	46.4	81.3	412.4	25.5	23.3	115	....	....	938	1,052	.89	5.17	2.90	7.1	33.1
55 to 60 meters......	6	58.3	89.4	511.2	26.7	27.5	130	....	....	1,093	1,314	.83	6.36	3.81	7.5	31.5
65 to 70 meters......	3	66.8	97.6	575.5	25.9	29.1	131	....	....	1,222	1,419	.86	6.92	4.23	7.4	31.8
70 to 75 meters......	7	73.8	102.9	628.6	26.4	31.1	127	....	....	1,345	1,567	.86	7.64	4.63	7.4	31.9
75 to 80 meters......	4	75.4	105.1	634.3	25.5	30.0	125	....	....	1,341	1,613	.83	7.81	4.79	7.5	31.1
80 to 85 meters......	6	81.3	107.1	685.0	26.3	33.5	134	....	....	1,481	1,712	.87	8.36	5.19	7.6	31.0
20 p. ct.:																
35 to 40 meters......	3	38.4	77.4	437.4	23.2	21.5	....	....	....	895	1,051	.85	5.11	3.09	7.1	33.0
45 to 50 meters......	3	45.2	82.5	514.9	23.4	23.3	109	....	....	996	1,176	.85	5.72	3.53	6.9	34.1
50 to 55 meters......	6	53.4	88.7	601.1	24.4	26.7	123	....	....	1,146	1,368	.84	6.63	4.27	7.1	33.0
65 to 70 meters......	9	67.4	101.8	772.6	25.4	34.2	126	....	....	1,529	1,685	.91	8.32	5.48	7.2	32.4
70 to 75 meters......	3	70.9	106.1	808.8	26.1	36.7	....	....	....	1,585	1,810	.88	8.86	6.09	7.6	31.0
75 to 80 meters......	2	79.5	109.9	924.9	25.9	41.5	....	....	....	1,987	2,190	.91	10.80	7.39	8.0	29.3
80 to 85 meters......	3	80.8	111.9	940.1	28.7	45.6	....	....	....	2,046	2,325	.88	11.41	7.96	8.5	27.6
25 p. ct.:																
40 to 45 meters......	3	42.6	84.9	628.1	23.8	29.1	....	....	....	1,183	1,451	.82	7.00	4.67	7.4	31.5
45 to 50 meters......	3	46.5	85.9	712.3	22.6	33.3	145	37.49	....	1,486	1,668	.89	8.20	5.73	8.0	29.2
50 to 60 meters......	4	54.3	93.3	809.2	24.7	37.5	148	37.97	....	1,614	1,831	.88	8.98	6.34	7.8	29.9
60 to 65 meters......	6	61.3	97.3	904.3	26.8	43.3	155	38.20	....	1,812	2,034	.89	9.99	7.18	7.9	29.5
65 to 70 meters......	3	68.9	104.8	1,001.8	27.3	46.8	....	38.15	....	2,023	2,231	.91	11.00	8.00	8.0	29.3
70 to 75 meters......	3	73.3	106.9	1,101.7	26.7	53.1	170	37.74	....	2,236	2,427	.92	12.02	8.83	8.0	29.1
75 to 80 meters......	2	76.5	108.1	1,154.5	27.6	58.5	176	37.78	....	2,405	2,541	.95	12.65	9.29	8.1	29.1
30 p. ct.:																
40 to 45 meters......	2	42.5	83.3	765.4	26.6	33.2	134	38.28	....	1,395	1,647	.84	8.00	5.68	7.4	31.7
45 to 50 meters......	7	48.8	95.3	887.4	27.6	40.6	135	37.28	....	1,619	1,826	.89	8.97	6.47	7.3	32.1
50 to 55 meters......	13	51.6	98.2	935.1	29.0	46.7	144	37.91	....	1,762	1,980	.89	9.72	7.16	7.7	30.6
55 to 60 meters......	2	57.6	98.0	1,036.5	27.3	44.5	161	38.83	....	1,965	2,201	.89	10.81	8.10	7.8	30.0
60 to 65 meters......	4	61.2	103.4	1,108.5	28.6	49.2	151	37.73	....	2,109	2,276	.92	11.28	8.46	7.7	30.6
65 to 70 meters......	11	68.4	108.5	1,240.9	29.1	55.5	159	37.68	....	2,360	2,524	.94	12.54	9.55	7.7	30.4
70 to 75 meters......	2	72.4	110.8	1,318.4	30.6	61.9	166	38.05	....	2,548	2,722	.94	13.52	10.39	7.9	29.6
35 p. ct.:																
45 to 50 meters......	3	44.8	96.0	937.3	27.7	40.5	145	38.29	....	1,732	2,007	.86	9.79	7.38	7.9	29.7
55 to 60 meters......	3	57.6	103.6	1,203.7	29.6	54.5	174	38.27	....	2,267	2,495	.91	12.31	9.60	8.0	29.4
60 to 65 meters......	2	62.4	102.9	1,306.3	29.1	61.8	177	38.08	....	2,507	2,725	.92	13.49	10.60	8.2	28.7
40 p. ct.:																
50 to 55 meters[1].....	6	51.8	95.0	1,245.2	30.3	56.8	163	38.10	....	2,317	2,481	.93	12.32	9.78	7.9	29.8
55 to 60 meters......	3	57.1	101.1	1,384.9	31.5	72.0	178	37.99	....	2,664	2,755	.97	13.79	11.02	8.0	29.3
65 to 70 meters......	2	65.2	103.4	1,568.8	35.0	84.5	186	38.29	....	3,017	3,132	.97	15.67	12.81	8.2	28.7
45 p. ct.:																
40 to 45 meters......	5	42.3	95.8	1,146.6	30.8	58.5	167	38.24	....	2,279	2,420	.94	12.04	9.78	8.6	27.4

---

[1] Includes one period with speed of 46 meters.

Carbon-Dioxide Elimination and Oxygen Consumption During Grade Walking.

The total carbon dioxide eliminated and oxygen consumed during the grade-walking experiments, as given chronologically in tables 13 to 16, show variations for the different periods of the individual days, but when we take into consideration the fact that the speed also varied to a certain extent for the different periods on each day, these variations in the carbon dioxide and oxygen appear to have no general significance, especially as they have no uniform relationship with the variations in the speed. On the other hand, when the data are grouped according to grade and speed, as is done in table 56, we find with any one grade that when the speed increases, that is, when the work performed increases, there is likewise an increase in the carbon dioxide and oxygen. We also find that both the carbon dioxide and oxygen with a low speed and high grade are lower than when the same amount of work is accomplished with a high speed and a low grade. This is also shown in the curves in figures 16 to 19, which are discussed later.

Table 57.—*Metabolism of W. K. and E. D. B., with maximum amount of work performed. (Values per minute.)*

Subject.	Date.	Work performed.	Carbon dioxide.	Oxygen.	Increase over standing requirement.	
					Carbon dioxide.	Oxygen.
		kg. m.	*c. c.*	*c. c.*	*p. ct.*	*p. ct.*
W. K.........	June 23, 1915	[1]891	2,152	2,094	1,057	818
E. D. B.......	Feb. 22, 1916	[1]1,569	3,017	3,132	1,416	1,205
M. A. M......	Mar. 6, 1912[2]	1,024	2,751	2,976	1,180	1,110
	May 10, 1914[3]	....	2,101	2,384	877	869

[1] Work due to grade-lift. See column *f*, tables 54 and 55.

[2] See Benedict and Cathcart, Carnegie Inst. Wash. Pub. No. 187, 1913, p. 64, table 74, and p. 124, table 116. The subject rode a bicycle ergometer.

[3] See Benedict and Murschhauser, Carnegie Inst. Wash. Pub. No. 231, 1915, p. 59. Standing values for same day for carbon dioxide and oxygen (215 c. c. and 246 c. c., respectively) used as base for computing increase for this period, also for March 6, 1912. The subject walked on a level.

The maximum daily averages for the two subjects who did the largest amounts of work (W. K. and E. D. B.) are given in table 57. For comparison, the maximum performance of M. A. M. on a bicycle ergometer in the study of Benedict and Cathcart,[1] and of the same subject walking on a level in the study of Benedict and Murschhauser[2] are included in the table. It should be stated, however, that whereas the values for W. K. and E. D. B. represent an average of data obtained in two periods of approximately 10 minutes each, the figures for

---

[1] Benedict and Cathcart, Carnegie Inst. Wash. Pub. No. 187, 1913, p. 64, table 74, and p. 124, table 116.

[2] Benedict and Murschhauser, Carnegie Inst. Wash. Pub. No. 231, 1915, p. 59.

M. A. M. in both cases represent measurements in only one period of the same length. By comparing these maximum values with the average standing requirements for the two subjects W. K. and E. D. B. (see tables 5 and 6, pp. 44 and 46), we find a percentage increase in the carbon-dioxide elimination and oxygen consumption of 1,057 and 818 per cent, respectively, for W. K., and 1,416 and 1,205 per cent, respectively, for E. D. B.

In figures 16 and 17 the total carbon-dioxide production per minute *versus* the kilogrammeters of work is plotted for the different grades for four of the subjects. From these curves it may be seen that the carbon-dioxide production per minute for all of the subjects increased uniformly with the increase in the amount of work performed. With both W. K. and E. D. B. the curves for the various grades show a general parallelism. The significant feature of these curves is, however, their relative position, in that the curve for the higher grade always lies beneath the curve for the next lower grade. For instance, in the curves for W. K. in figure 16, that for the 25 per cent grade lies below the curve for the 20 per cent grade, the curve for the 20 per cent grade lies below that for the 15 per cent grade, etc. As the work done is the product of the grade, body-weight, and distance walked per minute, and the body-weight may be taken as constant, when the same amount of work is performed with two different grades, this is due to a change in the speed of walking. The relative position of these curves shows, therefore, that while the men were able to accomplish identical amounts of work on the high and low grades by walking more rapidly on the low

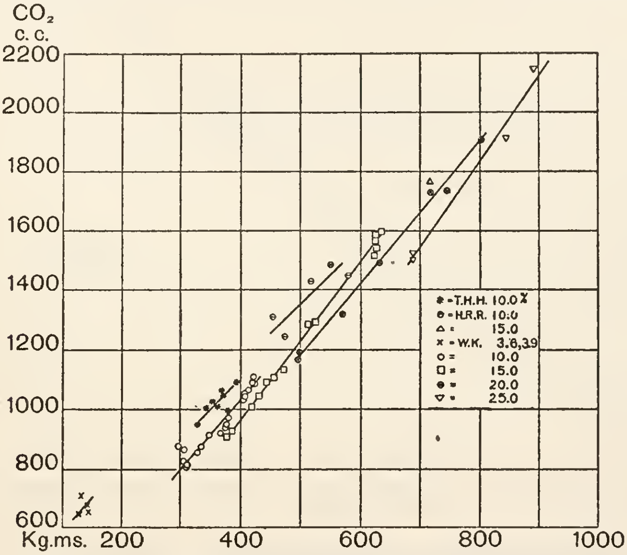

FIG. 16.—Total carbon-dioxide production of T. H. H., H. R. R., and W. K., referred to kilogrammeters of work performed in walking on different grades. (Values per minute.)

grade, in the performance of this work there was less economy in the metabolism with the lower grade.

Thus, from the curves for W. K., we find that in performing 700 kg. m. of work on a 25 per cent grade, he would produce 1,540 c. c. of carbon dioxide, while for the same amount of work on a 20 per cent grade the carbon-dioxide production would be 1,665 c. c. A like relation is seen to exist in the carbon-dioxide curves for E. D. B., 400 kg. m. of work on a 15 per cent grade costing 920 c. c. of carbon dioxide, whereas on a 10 per cent grade it would cost E. D. B. 1,030 c. c.

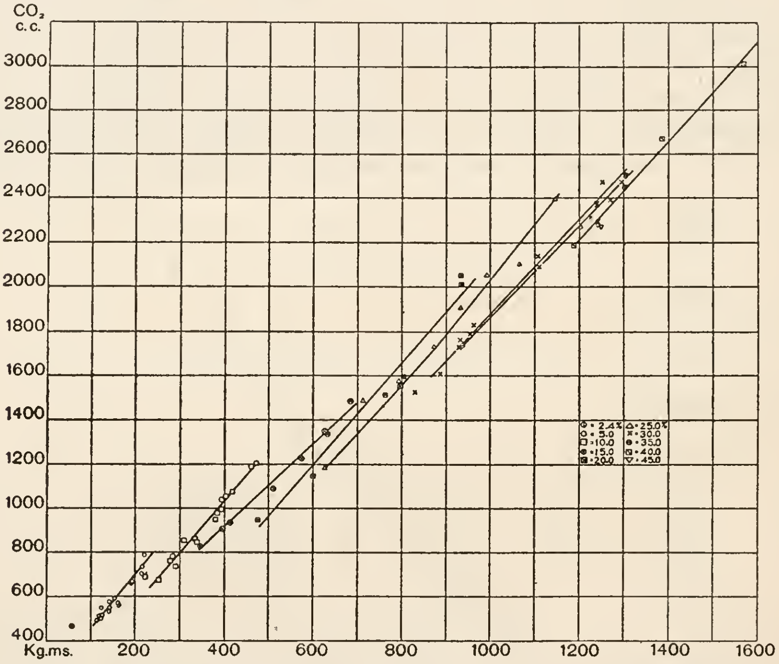

FIG. 17.—Total carbon-dioxide production of E. D. B., referred to kilogrammeters of work performed in walking on different grades. (Values per minute.)

The oxygen consumption per minute for the same four men has also been plotted on the basis of kilogrammeters of work, and the curves are given in figures 18 and 19. The general picture of the relationships is similar to that in figures 16 and 17, with reasonable uniformity between the increase in the oxygen consumption and the increase in the amount of work accomplished. The curves for E. D. B. for the higher grades (25 per cent and over) exhibit a tendency to change slightly in direction as compared with those for the lower grades.

While the range of work with W. K. was less than with E. D. B., the single curve for this subject above 20 per cent (that for a 25 per cent grade) indicates a similar tendency to change in direction at this point. The relative position of the curves with both subjects is usually like that found for the carbon-dioxide curves. With E. D. B., however,

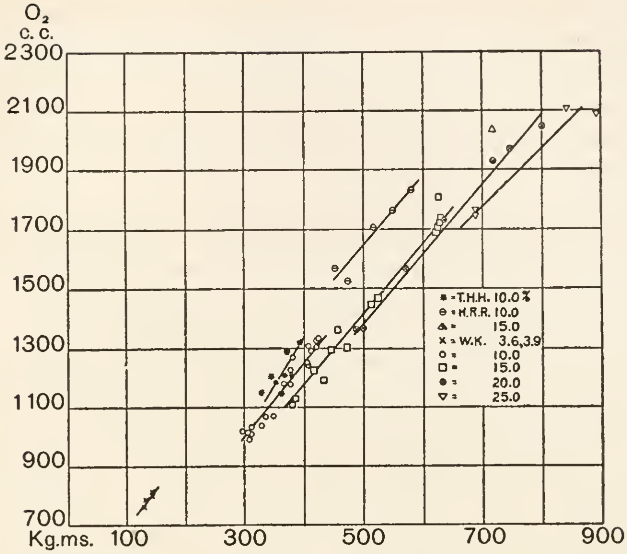

Fig. 18.—Total oxygen consumption of T. H. H., H. R. R., and W. K., referred to kilogrammeters of work performed in walking on different grades. (Values per minute.)

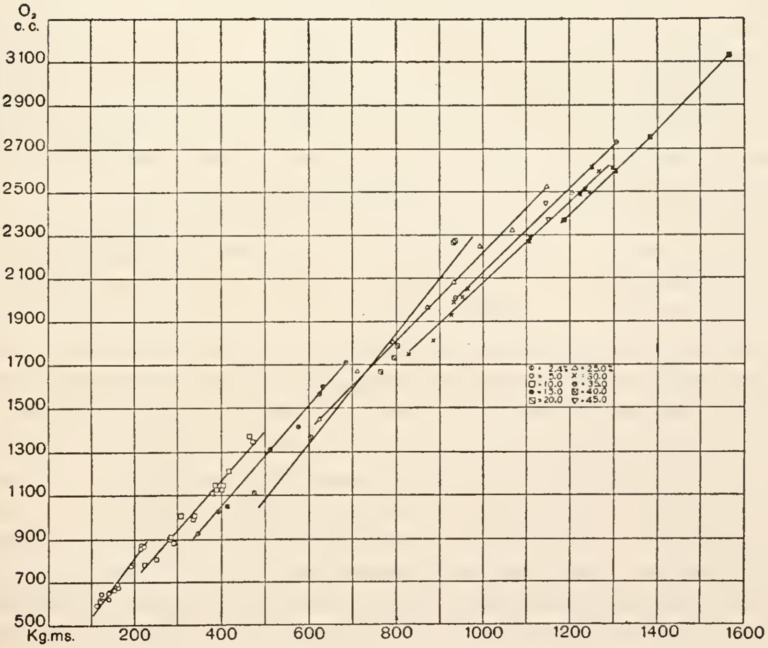

Fig. 19.—Total oxygen consumption of E. D. B., referred to kilogrammeters of work performed in walking on different grades. (Values per minute.)

it may be seen that the curve for the 35 per cent grade lies above that for the 30 per cent grade instead of slightly below it. This reverse in relationship is also found for the lowest point on the 25 per cent curve and for the two points for the 45 per cent grade, but these exceptions do not give sufficient cause for questioning the other curves, since the carbon-dioxide and oxygen curves for both subjects indicate that a definite amount of work can be performed at an optimum by intensifying the grade and lowering the speed. The general picture of these curves for both carbon dioxide and oxygen is that the relationship between the rate of increase in the metabolism and in the work performed is uniform within the ranges here reported.

The curves for the oxygen consumption of W. K. and E. D. B. in relation to the kilogrammeters of work are also presented in figures 23 and 24 (pp. 236 and 237), as plotted from the averages given in table 56, in which the data are grouped according to grade and speed.[1]

The curve for W. K. (fig. 23) indicates a slight change in trend in the region of 200 kg. m., but that of E. D. B. (fig. 24) is linear throughout the entire length. From the course of the curve for E. D. B., 425 c. c. per minute would appear to be the requirement for maintenance, horizontal increment, step-lift, etc., upon which the requirement for grade work *per se* is superimposed. The slope of the curve shows that on the average each kilogrammeter of grade work required an oxygen consumption of 1.7 c. c. throughout the range of E. D. B.'s endurance. The break in the curve for W. K. at 200 kg. m. makes an estimate of his requirements uncertain, but above 300 kg. m. his curve is linear, and from the slope of this part of the curve it would appear that the oxygen consumption was 1.95 c. c. for each kilogrammeter of work in the range studied, i. e., between 100 and 900 kg. m.

From the curves in figures 23 and 24 an estimate has been made for both W. K. and E. D. B. of the average oxygen consumption for increasing amounts of work performed. These figures are recorded in the second column of tables 58 and 59. The total and percentage increases over the standing requirement are likewise given. These tables show that, in the range covered, the increase in the total amount of oxygen consumed and both the total and the percentage increases over the standing requirement were larger for W. K. than for E. D. B. Thus, for 900 kg. m. (the maximum amount of work done by W. K.), the total oxygen consumption over the standing requirement was 1,982 c. c., or 869 per cent above the standing value for W. K., while for E. D. B. for an equal amount of work, the corresponding values were 1,740 c. c. of oxygen and 725 per cent above the standing requirement. It is also seen from these tables that it cost more per unit of 100 kg. m.

---

[1] The curves sketched through the points in these figures and also those in figures 28 and 29 for respiration-rate, pulmonary ventilation, and pulse-rate, represent the average of estimates made by three members of the Laboratory staff.

of work in the amount of oxygen consumed to perform smaller amounts of work than it did for a larger amount. Thus, per 100 kg. m. of work W. K. required 316 c. c. of oxygen above the standing requirement when 200 kg. m. of work were performed per minute and but 220 c. c. when 900 kg. m. of work were performed. That is, if

TABLE 58.—*Oxygen consumption of W. K. with increasing amounts of work in grade-walking experiments without food. (Values per minute.)*[1]

Kg.m. of work done.	Oxygen consumption.	Increase over standing requirement (228 c. c.).		Percentage increase over standing requirement.	
		Total.	Per 100 kg.m.	Total.	Per 100 kg.m.
	c. c.	*c. c.*	*c. c.*	*p. ct.*	*p. ct.*
200	860	632	316	277	139
300	1,030	802	267	352	117
400	1,230	1,002	251	439	110
500	1,420	1,192	238	523	105
600	1,620	1,392	232	610	102
700	1,810	1,582	226	694	99
800	2,000	1,772	222	777	97
900	2,210	1,982	220	869	97

[1]Estimated from curve in fig. 23, p. 236.

TABLE 59.—*Oxygen consumption of E. D. B. with increasing amounts of work in grade-walking experiments without food. (Values per minute.)*[1]

Kg. m. of work done.	Oxygen consumption.	Increase over standing requirement. (240 c. c.).		Percentage increase over standing requirement.	
		Total.	Per 100 kg. m.	Total.	Per 100 kg. m.
	c. c.	*c. c.*	*c. c.*	*p. ct.*	*p. ct.*
100	600	360	360	150	150
200	775	545	273	227	114
300	940	700	233	292	97
400	1,120	880	220	367	92
500	1,290	1,050	210	438	88
600	1,460	1,220	204	508	85
700	1,630	1,390	199	579	83
800	1,805	1,565	196	652	82
900	1,980	1,740	193	725	80
1,000	2,150	1,910	191	796	80
1,100	2,330	2,090	190	871	79
1,200	2,500	2,260	188	942	78
1,300	2,670	2,430	187	1,013	78
1,400	2,845	2,605	186	1,085	78
1,500	3,010	2,770	185	1,154	77
1,600	3,190	2,950	184	1,229	77

[1]Estimated from curve in fig. 24, p. 237.

the total energy expended above the standing requirement is charged to the work accomplished, a large amount of work is more economically performed than a small amount, since that portion of the energy requirement which might be regarded as a general or fixed charge is distributed over a larger return in the work accomplished.

Respiratory Quotient During Grade Walking.

The effect upon the respiratory quotient of varying amounts of work in grade walking may be seen from the data in tables 52 to 55 and in table 56. The obvious effect of work is to increase both the carbon dioxide produced and the oxygen consumed, with an accompanying increase in the pulmonary ventilation. If the increased ventilation of the lungs causes a sudden sweeping out of the preformed carbon dioxide in the blood before equilibrium with the oxygen demands can be met, the respiratory quotient is increased, or if the character of the metabolism is changed whereby the energy will be supplied from the carbohydrate store of the body rather than from the fat, the result will be an increase in the respiratory quotient.

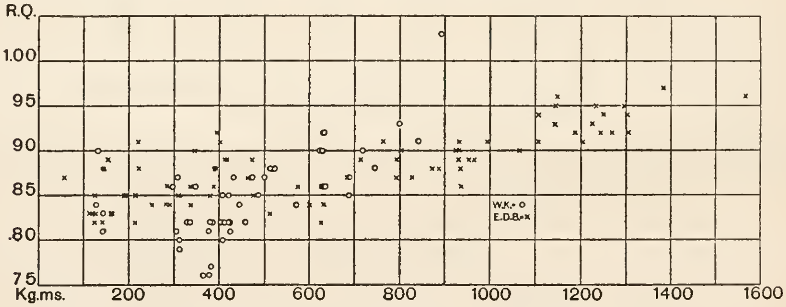

Fig. 20.—Respiratory quotients of W. K. and E. D. B. referred to kilogrammeters of work performed in grade walking. (Values per minute from table 56.)

The respiratory quotient of the normal subject in the post-absorptive condition is not far from 0.82 to 0.85, and from our measurements of the transition requirements (see p. 296), it would appear that the oxygen consumption and ventilation reached constancy within 2 or 3 minutes after the change from rest to work. As the subject walked 5 to 10 or more minutes previous to each period, it is therefore believed that before the period began the carbon dioxide and oxygen had become constant at the rate demanded by the work, and that the respiratory quotient would be of the average normal value unless an alteration in the character of the metabolism had taken place.

It is seen in table 56 (p. 221) that the average respiratory quotient for the different subjects was not different from the normal standing average for the lower grades and speeds, 0.87 being the highest average value found for any of the subjects below a 10 per cent grade at 60 to

65 meters per minute (about 2.5 miles an hour). It may also be seen that the respiratory quotient tended to increase as the grade and speed increased. This is more apparent in figure 20, in which the respiratory quotients for W. K. and E. D. B. given in table 56 have been plotted for experiments with varying degrees of work. In this chart the majority of the respiratory quotients up to approximately 600 kg. m. of work fall within the limits of 0.80 to 0.87, i. e., the normal post-absorptive respiratory quotients, and for 700 to 1,000 kg. m. of work, almost half of the respiratory quotients are 0.90 or above, while none are below 0.85. For more than 1,100 kg. m. the respiratory quotients are grouped around 0.93 and none are below 0.90, while the two determinations with work greater than 1,300 kg. m. give respiratory quotients of 0.97. Figure 20 gives clear indication that for such short periods as these, 600 kg. m. or less of work per minute do not tend to alter the character of the respiratory quotient, but with moderately heavy to heavy work, involving over 600 kg. m. per minute, the body alters its metabolism by a tendency to a selective consumption of its carbohydrate reserve.

TABLE 60.—*Comparison of respiratory quotients of E. D. B. during grade walking for the days of the week November 1 to December 11, 1915. (Subject in post-absorptive condition.)*

Day.	Nov. 1 to 6.		Nov. 8 to 13.		Nov. 15 to 20.		Nov. 22 to 27.		Nov. 29 to Dec. 4.		Dec. 6 to 11.	
	Work due to grade-lift.	Respiratory quotient.	Work due to grade-lift.	Respiratory quotient.	Work due to grade-lift.	Respiratory quotient.	Work due to grade-lift.	Respiratory quotient.	Work due to grade-lift.	Respiratory quotient.	Work due to grade-lift.	Respiratory quotient.
	kg. m.		*kg. m.*		*kg. m.*		*kg. m.*		*kg. m.*		*kg. m.*	
Mon...	143.5	0.88	155.0	0.89	222.4	0.91	250.5	0.84	387.7	0.86	346.6	0.90
Tues...	120.2	.83	161.1	.83	215.4	.82	337.3	.86	464.4	.87	412.4	.89
Wed...	124.7	.83	163.1	.83	289.9	.84	338.1	.84	474.4	.89	511.2	.83
Thurs..	140.7	.82	194.7	.85	....	....	....	(1)	403.5	.91	....	....
Fri....	124.1	.82	192.3	.85	....	....	395.9	[2].92	418.9	.89	....	....
Sat....	141.8	[3].88	217.5	.85	....	....	390.1	[4].88	393.7	.88	....	....

[1] Thanksgiving Day.
[2] Rock candy in supper preceding day.
[3] Molasses candy in supper preceding day.
[4] Candy and nuts in supper preceding day.

Zuntz and Schumburg[1] and Durig[2] have stated that work prolonged over a series of days tends to reduce the carbohydrate store in the body with a simultaneous lowering of the respiratory quotient and that a rest of one day in three is desirable in order to maintain a normal quotient. Contrary to the results of these authors, an inspection of the respiratory quotients for W. K. shows no evidence of a tendency for the quotient to decrease on successive days of walking with a subsequent increase on the omission of an experimental day. With E. D. B.

---

[1] Zuntz and Schumburg, Physiologie des Marsches, Berlin, 1901, p. 258.
[2] Durig, Arch. f. d. ges. Physiol., 1906, **113**, p. 263.

the quotients in the first few weeks of the series (in the untrained period) usually show higher values for the experiments on Mondays which followed the day of rest on Sunday. (See table 60.) Later in the study, and especially when the work became more intense, this is not apparent, for the later quotients follow no general trend, but are all on a higher level than those when the work of walking was lighter. With this subject it is possible that during the intermission on Sunday there was an accumulation of carbohydrate in the body which was drawn upon during the walking of Monday, thus raising the quotient for that day. If this were the case, the increase in the body carbohydrate appears to have been insufficient to supply the energy required to keep it at this higher level on the following days; accordingly there was a subsequent return of the quotient to the previous value. That no difference in the Monday quotients is apparent when the amount of walking became greater may be explained by saying that the increase in the metabolism due to the increase in the work may have been so large that this minor factor was lost sight of. Since our subjects were uncontrolled outside of the Laboratory, and, aside from the data regarding the last meal before the experiment, no detailed record was made of the diet, it is possible that the higher quotients on Monday have no special significance in this connection, except to show that some change in diet was made of which we have no knowledge, such as a possible indulgence in candy on the day of rest.

The absence of definite evidence in our results of the influence of a day of rest, as compared with the results found by the investigators referred to, may be due to a difference in the character of the experiments. With Zuntz and Schumburg the subject was carrying a load of approximately 25 kg.[1] while walking on a level at rates from 70 to 80 meters per minute. This does not allow a statement in terms of kilogrammeters, but the oxygen consumption was no greater nor as large, in many instances, as found for the subjects W. K. and E. D. B., who were walking up-grade without a load. Their subjects were controlled in their diet, while ours, as stated, were unrestrained, except for a 12-hour abstinence from food preceding the experiment. Evidently with W. K., and possibly with E. D. B., the work performed on these days was not such as to reduce the store of body carbohydrate to so great an extent that it could not be restored to a normal level during the resting hours of the remainder of the day and night.

After the writing of this report had been practically completed, the most interesting paper of Krogh and Lindhard,[2] entitled "The relative value of fat and carbohydrate as sources of muscular energy, with appendices on the correlation between standard metabolism and the respiratory quotient during rest and work," was received. The experience of the Nutrition Laboratory is wholly in line with their questioning the use of the mouthpiece in researches involving specifically a study of the respiratory quotient. Benedict and Murschhauser[1] emphasized the desirability of studying the metabolism during muscular work in a respiration chamber "with free breathing, without the use of either mouth or nose appliances." This Krogh and Lindhard have done with all of the niceties of detail characterizing Krogh's work. It is a cause for regret that since they stress especially the respiratory quotient as affected by muscular work, they did not include at least a few experiments with an oxygen consumption of from 1,500 to 3,000 c. c. per minute, as it was especially in regard to these periods of severe work that Benedict and Murschhauser made their recommendations as to method of study. Indeed, the results given in this present report (see table 56, p. 221) show high respiratory quotients, which, in the absence of demonstrated technical or physiological error, lead only to the conclusion that there is a specific, selective carbohydrate combustion with this intensity of performance.

---

[1] Zuntz and Schumburg, Physiologie des Marsches, Berlin, 1901, p. 249.

[2] Krogh and Lindhard, Biochem. Journ., 1920, **14**, p. 290.

TOTAL HEAT-OUTPUT DURING GRADE WALKING.

The total heat expended per minute during grade walking is given in tables 13 to 16, and also in column *j*, tables 52 to 55, and indicates the range of requirements for men of different weights at different grades and speeds. As the amount of heat produced is conditioned upon the work accomplished per minute, no direct comparison can be made except on the basis of kilogrammeters of work performed. These values, computed from the body-weight and grade-lift, are given in column *f* of tables 52 to 55.

The range in the total amounts of heat developed during grade walking is limited in the case of the two subjects, T. H. H. and H. R. R., as they dropped out of the study before any severe amount of work was performed. The range for W. K. is from 3.72 to 10.57 calories, with approximately 125 to 900 kg. m. of work, and for E. D. B. from 2.59 to 15.65 calories for work ranging from 59 to 1,569 kg. m. per minute. This last value is the average of two periods on February 22, when the subject walked up a 40 per cent grade at a rate of 65.2 meters per minute (2.50 miles an hour). The first period was of 10 minutes duration, with 13 minutes of preliminary walking. At the close of the period, the subject complained of pains in his chest and was doubtful of his ability to perform a second period of similar activity. The duration of the last period was reduced to 6 minutes after a preliminary walk of 5 minutes, as the subject showed signs of exhaustion.

If the values for the total heat-output per minute are plotted on the basis of kilogrammeters of work, as is done in figures 21 and 22, it is seen that the total heat-output is a linear function of the work performed for each grade. It appears from the relative positions of the curves for W. K. that the total heat produced for a given amount of work is somewhat higher when the work is performed at a fast rate of walking with a low grade. For instance, with 400 kg. m. of work on a 15 per cent grade, the total heat-output would be 5.62 calories, while with the same

---

[1] Benedict and Murschhauser, Carnegie Inst. Wash. Pub. No. 231, 1915, p. 30.

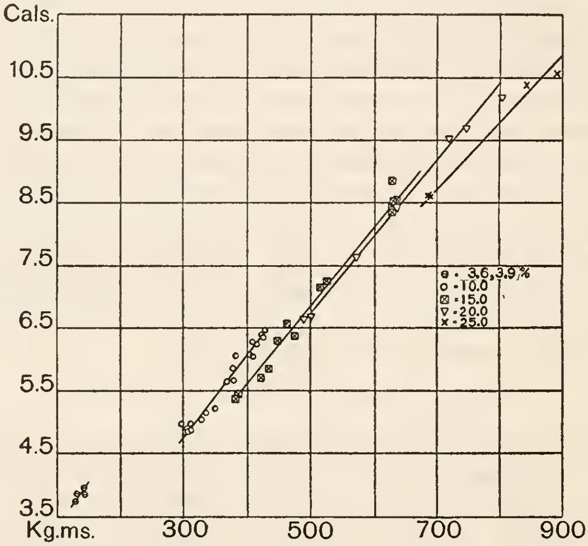

FIG. 21.—Total heat-output of W. K., referred to kilogrammeters of work performed in walking on different grades. (Values per minute.)

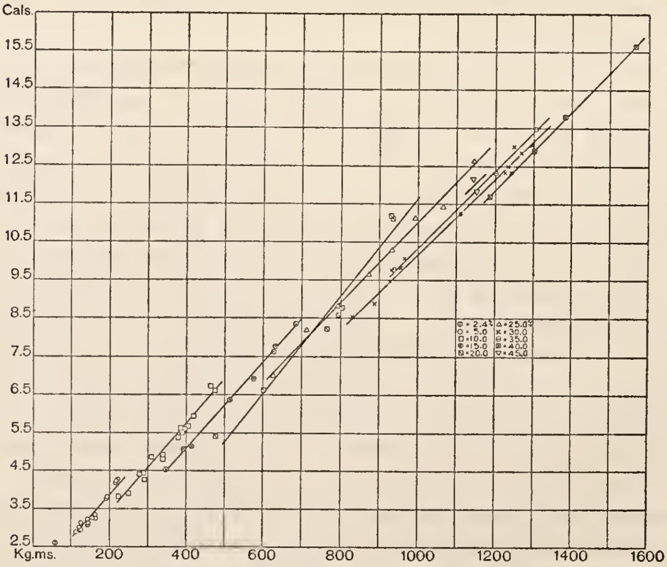

FIG. 22.—Total heat-output of E. D. B., referred to kilogrammeters of work performed in walking on different grades. (Values per minute.)

amount of work due to faster walking on a 10 per cent grade it would be 6.08 calories. This characteristic was also apparent from the relative positions of the curves for the total carbon dioxide and oxygen for both W. K. and E. D. B., given in figures 16 to 19. While most of the curves for the heat-output of E. D. B. show this same relationship between the heat produced for a definite amount of kilogrammeters of work with different grades, the curve for the 35 per cent grade and a part of the curve for the 25 per cent grade, as well as the two points for the 45 per cent grade, indicate a higher heat-output than is found for the same number of kilogrammeters of work on the curve for the next lower grade. These exceptions were also found with the oxygen curves, as discussed on page 228.

TABLE 61.—*Minimum and maximum heat-output in grade walking during experiments without food. (Values per minute.)*

Subject.	Minimum heat-output.	Work due to grade-lift.	Heat per kg. m. of grade-lift.	Maximum heat-output.	Work due to grade-lift.	Heat per kg. m. of grade-lift.
	cals.	*kg. m.*	*gm.-cals.*	*cals.*	*kg. m.*	*gm.-cals.*
H. R. R.....	7.36	475	15.5	9.95	717	13.9
T. H. H.....	5.59	328	17.0	6.39	392	16.3
W. K........	3.72	129	28.8	10.57	891	11.9
E. D. B......	2.59	59	43.9	15.65	1,569	10.0

TABLE 62.—*Comparison for E. D. B. of total heat-output per kilogrammeter of work in grade walking with increasing amounts of work. (Values per minute.)*

Date.	Work due to grade-lift.	Total heat.	Heat per kg. m. of grade-lift.
	kg. m.	*cals.*	*gm.-cals.*
Apr. 15..	59	2.59	43.9
14..	126	3.14	24.9
8..	223	3.84	17.2
Mar. 24..	310	4.88	15.7
23..	380	5.39	14.2
Dec. 13..	576	6.92	12.0
Jan. 5..	993	11.12	11.2
Feb. 11..	1,250	13.00	10.4
22..	1,569	15.65	10.0

The minimum and maximum daily averages for the total heat-output of H. R. R., T. H. H., W. K., and E. D. B., together with the amount of work done on these days, are given in table 61. For comparison, the total heat-output per kilogrammeter of vertical grade-lift, or the total energy cost for 1 kg. m. of work done in the elevation of the body, has also been calculated for these days and included in the table. As the basal requirements form a part of these total values, the cost per kilogrammeter of work is naturally larger when the work is small and decreases with increasing work. This is clearly seen from the figures collected in table 62, in which the data for E. D. B. for increasing amounts of work are given in a more extended form than in table 61. The total heat cost per kilogrammeter is here shown to decrease rapidly at first, with increasing amounts of work, but soon reaches a limit; above 1,000 kg. m. the total cost is approximately constant at 10 gram-calories per kilogrammeter of work of grade-lift. The fact that the total heat-output per kilogrammeter of work accomplished is less for a steep grade and slower speed than for a low grade and a high speed, as seen from the relative positions of the curves in figure 21 and with most of the curves in figure 22, and that the heat-output per kilogrammeter is lowest when the largest amount of work is done in unit time, as seen in table 62, may explain why many trained walkers prefer a short and steep ascent to a more circuitous and gradual one.

Curves for the average total heat-output of W. K. and E. D. B. with different amounts of work, due to varying grades and speeds, are included in figures 23 and 24. These curves are based upon the data in table 56, in which the values are grouped according to grade and rate of walking. The curve for W. K. indicates a slight tendency to deviate from a straight line at the lowest point, but that for E. D. B. is linear throughout its entire length of 1,600 kg. m. If we estimate the basal

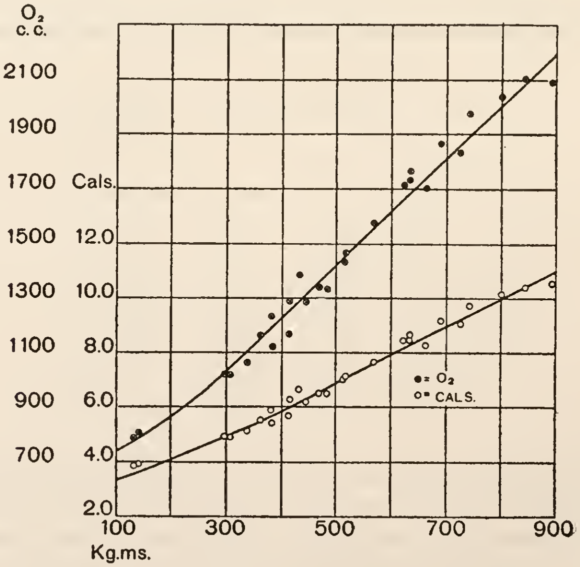

Fig. 23.—Total oxygen consumption and heat-production of W. K., referred to kilogrammeters of work performed in grade walking. (Values per minute from table 56.)

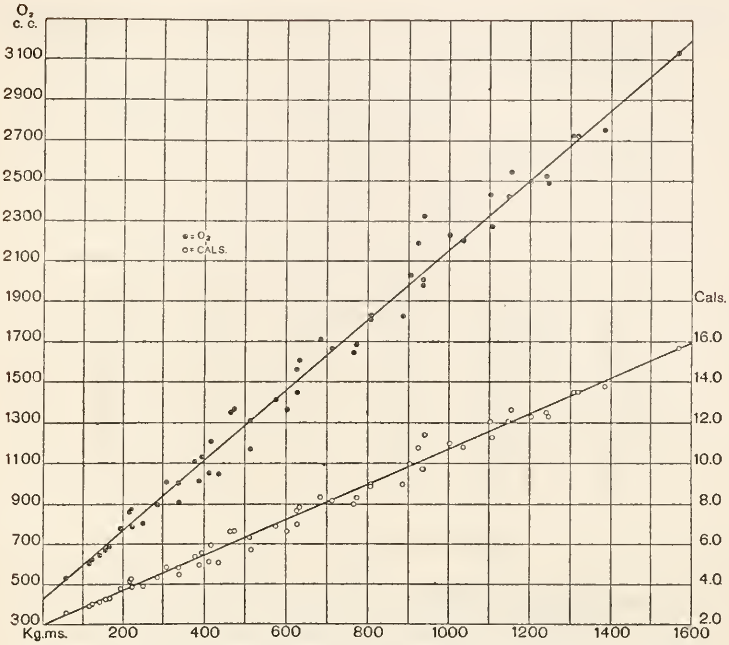

FIG. 24.—Total oxygen consumption and heat-production of E. D. B., referred to kilogrammeters of work performed in grade walking. (Values per minute from table 56.)

requirement of E. D. B., as was done in considering the curve for the oxygen consumption given in the same figure (see p. 228), we find his requirement for maintenance, horizontal component, step-lift, etc., to be 2.00 calories, and superimposed on this is the average requirement of 8.7 gram-calories for each kilogrammeter of work due to grade-lift. Since the curve for W. K. is not linear throughout, no definite estimate can be made for his basal requirement, but the slope of the line above 400 kg. m. would indicate that the requirement for each kilogrammeter of work due to grade-lift was 10.5 gram-calories.

The total heat-output as estimated from the curves in figures 23 and 24 for increasing amounts of work, also the increase over the standing requirements due to the work performed, are recorded in tables 63 and 64. It is seen in comparing these sets of figures, as was done with tables 58 and 59, that of the two subjects W. K. spent the larger amount of heat over the standing requirement for a given amount of work, and also that the heat expended per unit of 100 kg. m. in excess of the standing requirement was greater for small than for large amounts of work. In both cases the increment in the heat per 100 kg. m. decreased rapidly, approximating a value of 1.10 calories for W. K. and 0.96 calorie for E. D. B. for 800 to 900 kg. m., while for 1,500 to 1,600 kg. m. the value for E. D. B. was slightly less, i. e., 0.92 calorie.

Table 63.—*Total heat-output of W. K., with increasing amounts of work, in grade-walking experiments without food.* (*Values per minute.*)[1]

Kg. m. of work done.	Heat-output.	Increase over standing requirement. (1.10 cals.)		Percentage increase over standing requirement.	
		Total	Per 100 kg. m.	Total.	Per 100 kg. m.
	cals.	*cals.*	*cals.*	*p. ct.*	*p. ct.*
100	3.35	2.25	2.25	205	205
200	4.10	3.00	1.50	273	137
300	4.95	3.85	1.28	350	116
400	5.80	4.70	1.18	427	107
500	6.90	5.80	1.16	527	105
600	7.90	6.80	1.13	618	103
700	9.00	7.90	1.13	718	103
800	10.00	8.90	1.11	809	101
900	11.00	9.90	1.10	900	100

[1] Estimated from curve in figure 23.

Table 64.—*Total heat-output of E. D. B., with increasing amounts of work, in grade-walking experiments without food.* (*Values per minute.*)[1]

Kg. m. of work done.	Heat-output.	Increase over standing requirement. (1.16 cals.)		Percentage increase over standing requirement.	
		Total	Per 100 kg. m.	Total.	Per 100 kg. m.
	cals.	*cals.*	*cals.*	*p. ct.*	*p. ct.*
100	2.85	1.69	1.69	146	146
200	3.70	2.54	1.27	219	110
300	4.60	3.44	1.15	297	99
400	5.50	4.34	1.09	374	94
500	6.35	5.19	1.04	447	89
600	7.25	6.09	1.02	525	88
700	8.10	6.94	.99	598	85
800	8.95	7.79	.97	672	84
900	9.80	8.64	.96	745	83
1,000	10.70	9.54	.95	822	82
1,100	11.60	10.44	.95	900	82
1,200	12.45	11.29	.94	973	81
1,300	13.30	12.14	.93	1,047	80
1,400	14.20	13.04	.93	1,124	80
1,500	15.05	13.89	.93	1,197	80
1,600	15.90	14.74	.92	1,271	79

[1] Estimated from curve in figure 24.

INCREMENT IN HEAT-OUTPUT DUE TO GRADE-LIFT.

TOTAL INCREMENT IN HEAT DUE TO GRADE-LIFT.

That portion of the total heat expended during grade walking that is due to the grade *per se* is the total heat-output less the energy requirements for standing and horizontal walking. This difference is

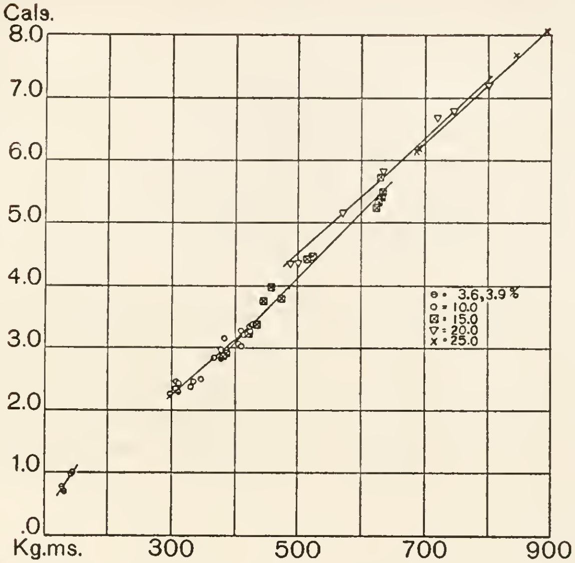

FIG. 25.—Daily increments in heat-production over standing requirement and horizontal component, referred to kilogrammeters of work done in walking experiments on different grades with W. K. (Values per minute.)

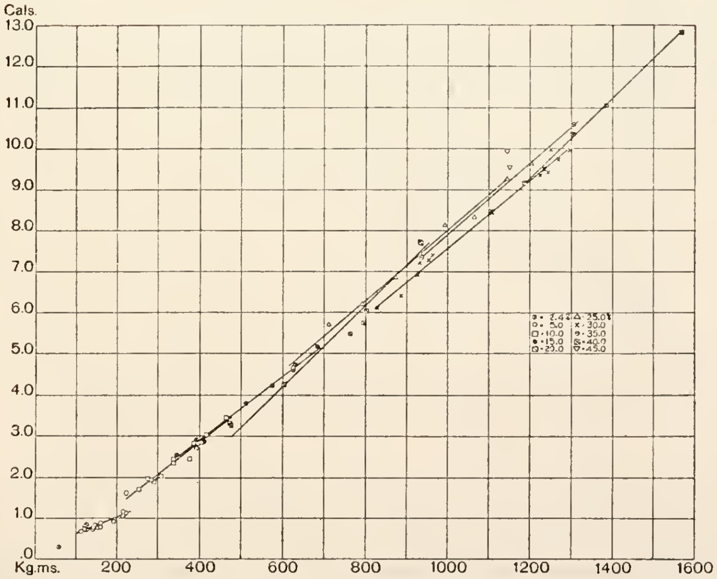

FIG. 26.—Daily increments in heat-production over standing requirement and horizontal component, referred to kilogrammeters of work done in walking experiments on different grades with E. D. B. (Values per minute.)

recorded in column *o* of tables 52 to 55. The standing requirements in tables 3 to 7 and the increments due to walking on a level given in tables 29 to 33 are used for obtaining the total requirements for these two factors. The values used for deduction were either determined on the same day or represent an average value, the selections being noted in the footnotes to tables 52 to 55. These increments in the heat-output which are due specifically to the grade have been plotted for W. K. and E. D. B. for each grade on the basis of kilogrammeters of work. (See figs. 25 and 26.) It is seen in these figures that the heat increment is a linear function of the work done, as was the total heat (see figs. 21 and 22), but in these curves, with the basal and horizontal requirements eliminated, the amounts of heat produced for the same amounts of work with different grades more nearly coincide and the curves as a whole make a more nearly uniform and continuous grouping, thus indicating that the heat increment is practically independent of whether the given amount of work is produced by altering the rate of walking or the grade.

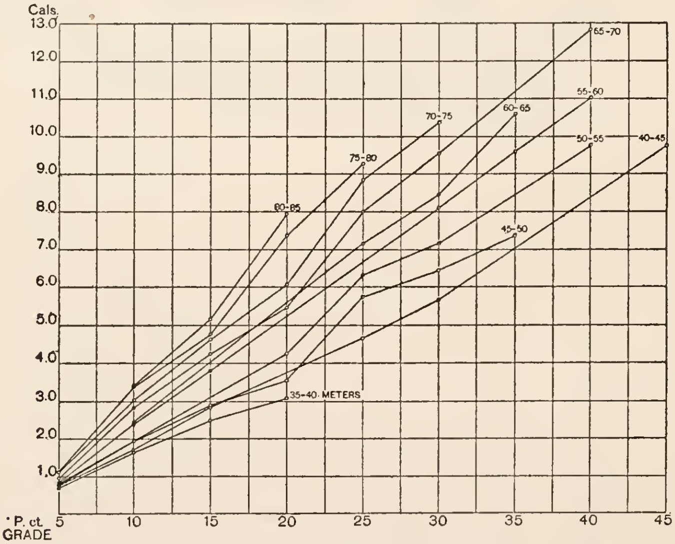

FIG. 27.—Average increments in heat-production due to grade-lift in walking experiments with E. D. B. (Values per minute from table 56.)

To show the relation between the increment in the heat-output and the grade and speed used in walking, the data for E. D. B. in table 56 have been plotted for the various speeds and grades and the curves given in figure 27. It will be seen from these curves that a change in speed from 35–40 meters to 75–80 meters per minute (or approximately 1.5 to 3 miles per hour) on a 20 per cent grade increased the heat-output due to the grade walking approximately 4.5 calories, while a change from a 5 per cent grade to a 20 per cent grade increased this factor about 2.25 calories when E. D. B. walked at 35 to 40 meters per minute, and about 6.25 calories when he walked at 75 to 80 meters per minute.

These changes may be calculated on a percentage basis by referring to the values in column *m* of table 56 (p. 221). Thus, a change in speed from 35–40 meters per minute to 75–80 meters per minute increased the heat-output over that required for standing and the horizontal component 0.42 calorie, or 60 per cent, with a 5 per cent grade; 1.76 calories, or 108 per cent, with a 10 per cent grade; 2.29 calories, or 92 per cent, with a 15 per cent grade; and 4.30 calories, or 139 per cent, with a 20 per cent grade. When the subject was walking with a speed of 35 to 40 meters and on a 5 per cent grade, the heat-output due to grade walking averaged 0.70 calorie. When he changed to a grade of 10 per cent without change of speed, the heat-output increased 0.93 calorie, or 133 per cent; with a 15 per cent grade, the increase over the 5 per cent value was 1.8 calories, or 257 per cent; and with a 20 per cent grade, 2.39 calories, or 341 per cent. Similarly, when the speed of walking was 75 to 80 meters per minute, the percentage increases over the 5 per cent grade were 203 per cent for the 10 per cent grade, 328 per cent for the 15 per cent grade, 560 per cent for the 20 per cent grade, and 729 per cent for the 25 per cent grade.

INCREMENT IN HEAT PER KILOGRAMMETER OF WORK DONE IN GRADE-LIFT.

From the increment in the heat-output due to the grade and the total kilogrammeters of work due to the grade-lift, the heat outlay per kilogrammeter of work done in the elevation of the body has been computed and recorded in column *p* of tables 52 to 55. A summary of the daily averages is given in table 65. A. J. O., with only one experiment of two periods, shows the lowest average value, or 5.6 gram-calories. This was for the low grade of 3.6 per cent, with but 172 kg. m. of work. The total heat-output was correspondingly low and the proportionate probability of error on deducting the values for the standing and horizontal walking requirements was naturally large.

TABLE 65.—*Average increment in heat-output due to grade-lift per kilogrammeter of work.*

Subject.	No. of experiments.	Minimum increment.	Maximum increment.	Average increment.
		gm.-cals.	*gm.-cals.*	*gm.-cals.*
A. J. O. . .	1	. . . .	. . . .	5.6
H. R. R. .	6	7.2	8.0	7.5
T. H. H. .	8	6.8	8.1	7.6
W. K.	48	5.3	9.3	8.1
E. D. B. . .	79	4.8	8.7	7.0
Average.	. . . .	6.0	8.5	7.2

The values for H. R. R. were fairly uniform, averaging 7.5 gram-calories, with a range in work performed of 452 to 717 kg. m. The highest value of 8.0 gram-calories was in the one experiment with a 15 per cent grade. T. H. H. also performed his task at an average energy cost of 7.6 gram-calories, although his daily work did not exceed 392 kg. m. as compared with 717 kg. m. for H. R. R.

W. K. on his first day, with a 3.6 per cent grade, did only 131 kg. m. of work, and his low heat cost for this work of 5.3 gram-calories may be assumed as due largely to the difficulty of measuring the heat differences in these small amounts. His maximum cost was 9.3 gram-calories when 719 kg. m. of work were done and the average value 8.1 gram-calories.

With E. D. B. the range was wider than for any of the five men. His lowest daily cost per kilogrammeter was 4.8 gram-calories, and a closely approximate value was found on several other days. Although these low values are not necessarily for the period of the least amount of work, in all but one case the work performed was below 200 kg. m. and the heat due to the grade work as computed constitutes approximately but one-fourth of the total heat measured. These low values appear both in the early period of grade walking and again on the last day, when a 2.5 per cent grade was walked, with an outlay of 59 kg. m. It seems probable, therefore, that the low increment in the heat-output per kilogrammeter found with A. J. O., W. K., and E. D. B. is due to the method of apportioning the heat for standing and horizontal walking requirements, rather than to the fact that the values were actually low. The average increment due to grade-lift for E. D. B. was 7.0 gram-calories, and for the group of five subjects, 7.2 gram-calories. Omitting A. J. O. from the average, since he had but one experiment, the average value for the four remaining subjects is 7.6 gram-calories per kilogrammeter of work done.

In the discussion of the results of the horizontal-walking experiments, it was seen that some evidence of a training effect appeared in the later experiments with E. D. B. (See tables 34 and 43, pp. 141 and 159.) The data obtained in the experiments on grade walking do not offer so great an opportunity for a study of the effect of training upon the oxygen consumption and the heat-production with a definite amount of work as might be expected, owing to the difference in the conditions of the experiments and to the more or less progressive increase in work as the research continued. This increase in work was due to the fact that in the earlier experiments the lower grades were used when the subject was less practiced in walking, and as the series progressed the grades were gradually increased, so that in the later experiments the higher grades were used when the subject may be said to have been trained in walking. Near the close of E. D. B.'s five months of service as a subject, low grades were again used in a few experiments, and these are the only results which are at all comparable with data obtained in the earlier part of the series, when the subject was untrained. These low-grade experiments were, however, so few in number and, particularly, the total amount of work was so small, being in all cases under 300 kg. m. per minute, that the data do not lend themselves to the critical discussion of the effect of training upon the energy cost per kilogrammeter of work done in walking up-grade.

Step-Lift During Grade Walking.

The measurement of the step-lift during horizontal walking is comparatively simple as determined by the revolution of the work-adder wheel, supplemented and controlled at times by the kymograph tracings of the spring pointer of Dr. C. Tigerstedt.[1] (See p. 30.) The results of these measurements have been discussed in an earlier section. (See p. 155.)

An attempt was made to measure the step-lift in grade walking by the method used in the horizontal-walking experiments. There is, however, a decidedly different type of step-lift in grade walking as compared to that in walking on a level, for in grade walking the weight is of necessity thrown more on the toes than in walking on a horizontal plane and the center of gravity must be farther forward. In the grade-walking experiments the body continually moved up an inclined plane (the treadmill belt), which, to be sure, was continually passing by the body of the subject. Was any of the movement recorded as step-lift actually due to the "grade-lift" of the body, or was the record an uncontaminated measure of the particular type of step-lift necessarily accompanying grade walking? It was considered that the position of the subject on the treadmill was so closely determined by the mouthpiece and the fork of the step-lift recorder which rested on his shoulder (see fig. 1, p. 19) that he could alter his relative position on the treadmill but little. This supposition has been confirmed by the photographic tests previously described on page 31. It is recognized, however, that possibilities of error in these measurements are present, as was the case with the measurements for walking on a level.

As pointed out in the description of the technique (p. 33), the manner of measuring the step-lift in these experiments is fairly open to criticism as to the position of the fork. (See fig. 1, p. 19.) After the preparation of this manuscript was nearly completed, it seemed desirable to make tests to note the influence, if any, of a change in position of the fork with relation to the plane upon which the subject walks.[2] Consequently, the mill was set at a 30 per cent grade and the fork was placed in a position parallel to the belt of the mill. Under these conditions the cord attached to the fork and leading to the kymograph passed upwards in a direction perpendicular to the plane of the mill to a pulley above, thence to a second pulley, and thence to the kymograph.

---

[1] C. Tigerstedt, Skand. Arch. f. Physiol., 1913, **30**, p. 299.

[2] The author wishes to acknowledge his indebtedness to Dr. F. G. Benedict, who carried out these experiments at a time when he himself was unable to co-operate.

Unfortunately, none of the original subjects in this research could be secured for the later tests, as they were no longer in the vicinity of Boston. Consequently, another subject was used, and tests were made with the fork not only in the new position, but also for comparison in the position used in the research. No measurements of the metabolism accompanied these tests. Two speeds of walking were employed, one approximately 50 to 55 meters per minute and another from 75 to 87 meters per minute. The results show that when the fork was parallel to the treadmill belt there was, as a matter of fact, a somewhat greater step-lift than when the fork was left in the original position. (See fig. 1.)

The string was then attached at the belt of the subject in the position originally used by Benedict and Murschhauser[1] and the results compared with those obtained with the fork parallel to the treadmill belt. Very satisfactory agreement was obtained in all cases. The important point brought out in this test is that the step-lift as measured by the method employed in the entire research reported in this publication, namely, with the fork parallel to the floor and not to the angle of ascent, is in all probability somewhat too small rather than too large. In the absence of the original subjects, particularly E. D. B., it seemed undesirable to make an attempt to establish closely related correction factors by comparing the step-lift during grade walking as measured with the probable step-lift measured with the fork in what we now believe to be the proper position, i. e., parallel to the surface of the treadmill.

The method of studying the locomotion of man, devised by Braune and Fischer,[2] is extraordinarily ingenious. No one who reads their original memoir and the subsequent analyses by Fischer can fail to be impressed by this profitable method of attack. It is particularly unfortunate for us that, if experiments were made by these authors on grade walking, no photographic results were given and no data published. Had this been the case, we feel sure that the element of uncertainty as to the step-lift in grade walking would have been quickly dispelled.

Apparently from purely theoretical considerations, Amar[3] has sketched the hypothetical movements of the body in grade walking and clearly indicates a somewhat higher oscillatory motion perpendicular to the plane of the belt than would obtain in horizontal walking.

---

[1] Benedict and Murschhauser, Carnegie Inst. Wash. Pub. No. 231, 1915, pp. 32 and 40.

[2] Braune and Fischer, Abhandl. d. math.-phys. Klasse d. Konigl. Sächsischen Gesellsch. d. Wissensch., Leipsic, 1895, **21**, p. 153.

[3] Amar, Le moteur humain, Paris, 1914, p. 476.

Step-lift per minute.—In considering the step-lift per minute, recorded in column *g* of tables 52 to 55, it is seen that although the variations present in horizontal walking between experimental periods with like conditions are likewise to be found here, the amount of lift per minute increased in approximate conformity with the speed for the same grade. It may also be noted that the lift per minute for the same or approximately the same speed increased with the grade, and that the total lift reached a very appreciable amount at the higher grades and speeds. Thus, E. D. B. had a total step-lift per minute of 7.1 meters when walking on a 30 per cent grade at 69.5 meters per minute and on a 40 per cent grade at 65 meters per minute, as compared with a total step-lift per minute of 1.7 meters on a 5 per cent grade at 65.4 meters per minute. (See table 55, p. 209.)

Step-lift per step.—The lift per step likewise shows an increase with the higher grades and speeds. W. K., on March 4, walking on a 3.6 per cent grade at 69 meters and 114 steps per minute, had a lift per step of 1.2 cm., while on June 17, on a 25 per cent grade at 67 meters and 120 steps per minute, it was 4.6 cm. (See tables 15 and 54, pp. 71 and 199.) A summary of the data obtained for the lift per step of E. D. B. during grade walking is given in table 66, grouped according to grade and speed. The values for horizontal walking (0 per cent grade) are also given for comparison. The lift per step for E. D. B. with a 5 per cent grade and a speed below 60 meters per minute was 1.36 cm., only slightly greater than the average found during horizontal walking (1.18 cm.) for approximately the same speed. For the highest grades and speeds, however, the lift per step was between 6 and 7 cm.

TABLE 66.—*Average step-lift per step of E. D. B. in grade walking for approximately the same speeds but with varying grades. (Values per minute.)*

Per cent grade.	Step-lift per step at speed of—		
	Less than 60 meters.	60 to 70 meters.	70 to 80 meters.
	cm.	*cm.*	*cm.*
0	1.18	2.05	2.53
5	1.36	1.85	2.63
10	2.50	3.68	4.06
15	3.13	3.95	4.78
20	4.04	4.98	4.69
25	4.61	5.68	6.36
30	5.38	5.94	....
35	5.43	6.57	....
40	6.18	6.88	....
45	5.84	....	....

COMPARISON OF STEP-LIFT IN HORIZONTAL AND GRADE WALKING.

Although the data for the step-lift as measured may be found scattered throughout the tables, it seems desirable to make a direct comparison of the step-lift in horizontal walking with the step-lift in grade walking as measured by the apparatus pictured in figure 1. Such comparison should, however, be subject to the criticism and at least theoretical corrections brought out in the discussion of the technique on page 31. Using the data for our most frequently employed subject, E. D. B., we have collected in table 67 a series of values comparing the step-lift of this subject during horizontal and grade walking at an average speed of 45 meters. The different grades used in the grade-walking experiments are also indicated. The first half of the table consists simply of a repetition of horizontal walking on different days, and consequently shows no great variation. As a matter of fact, the total step-lift ranged from 0.66 to 1.00 meter per minute on the days selected for comparison, and the step-lift per step from 0.82 to 1.18 cm. Since all of the horizontal-walking data are not here included, it seems unnecessary to assume an average, and it will not be used in the subsequent discussion.

TABLE 67.—*Comparison of step-lift of E. D. B. in horizontal and grade walking at an approximate speed of 45 meters. (Values per minute.)*

Date and conditions.	Grade.	Distance walked.	No. of steps.	Length of step.	Step-lift.	Step-lift per step.
1915.						
Horizontal walking:	*p. ct.*	*meters.*		*cm.*	*meters.*	*cm.*
Oct. 30	....	43.9	80.3	54.7	0.66	0.82
Nov. 1	....	44.3	79.7	55.6	.72	.90
2	....	43.2	79.9	54.1	.70	.88
3	....	44.5	85.3	52.2	.76	.89
5	....	46.2	81.9	56.4	.81	.99
6	....	45.9	80.8	56.8	.75	.93
10	....	47.8	84.7	56.4	1.00	1.18
17	....	45.7	79.0	57.8	.78	.99
22	....	47.4	80.7	58.7	.79	.98
Dec. 4	....	46.7	79.0	59.1	.93	1.18
6	....	45.0	78.5	57.3	.68	.87
7	....	45.8	77.1	59.4	.67	.87
Grade walking:						
Nov. 4	5.0	48.2	79.9	60.3	0.99	1.24
6	5.0	48.2	79.5	60.6	1.00	1.26
17	10.3	48.0	81.1	59.2	1.86	2.29
Dec. 7	15.0	46.4	81.3	57.1	2.42	2.98
1916.						
Feb. 2	25.0	46.5	85.9	54.1	4.31	5.02
8	30.0	46.0	88.8	51.8	4.60	5.18
18	40.0	49.5	89.9	55.1	5.64	6.27

The values for the grade walking are given in the lower part of the table. It will be noted that the distance walked per minute was slightly higher in most instances than in the horizontal walking. Notwithstanding the somewhat greater speed in grade walking, the number of steps was not, as a rule, larger than in horizontal walking until a grade of 25 per cent was reached; thereafter the number of steps taken per minute was larger. The step-lift increased very perceptibly with the grade and likewise the step-lift per step.

In table 68 a similar comparison is made when the average speed for both horizontal and grade walking was 77 meters per minute. In the upper part of the table the data for horizontal walking are more or less representative of duplicate experiments on different days and show no great variation. During the grade walking there was, as with the slower speed, a very perceptible increase in the number of steps with the higher grades, beginning at 20 per cent, although it is again to be noted that in three of the four tests in grade walking the actual rate of walking per minute was somewhat higher than during the horizontal walking. The step-lift increased pronouncedly, as did the step-lift per step.

TABLE 68.—*Comparison of step-lift of E. D. B. in horizontal and grade walking at an approximate speed of 77 meters. (Values per minute.)*

Date and conditions.	Grade.	Distance walked.	No. of steps.	Length of step.	Step-lift.	Step-lift per step.
1915 Horizontal walking:	*p. ct.*	*meters.*		*cm.*	*meters.*	*cm.*
Oct. 27		77.7	104.5	74.4	2.91	2.78
28		77.8	106.5	73.1	2.78	2.61
29		78.0	104.8	74.4	2.95	2.81
Nov. 13		76.7	103.9	73.8	2.75	2.65
15		77.0	104.0	74.0	2.83	2.72
16		76.9	103.7	74.2	2.90	2.80
19		77.9	104.1	74.8	2.43	2.33
Dec. 1		76.2	105.3	72.4	2.72	2.58
Grade walking:						
Nov. 30	10	78.5	101.7	77.2	4.05	3.98
Dec. 16	15	81.3	107.1	75.9	5.17	4.83
31	20	80.1	110.2	72.7	4.69	4.26
1916. Feb. 7	25	75.9	109.3	69.4	6.95	6.36

It was a special consideration of these latter factors, namely, the step-lift and the step-lift per step, that led us to surmise that the method of measurement of the step-lift indicated in figure 1, i. e., with the fork parallel to the floor and not parallel to the plane of walking, might incorporate in the graphic record a certain component that should properly be ascribed to the grade-lift. This surmise led to the series of experiments reported on page 243, from which the conclusion is drawn from tests made on a single subject (unfortunately not one of the original group) that the step-lift as measured was probably not contaminated by grade-lift, but, if anything, with the fork parallel to the floor, the apparatus does not record so large oscillations of the shoulders in a direction perpendicular to the inclined plane of the belt as it does when the fork is parallel to the belt. It is assumed, therefore, in subsequent discussion, that the step-lift as actually measured and recorded in this publication is not far from correct, though probably somewhat below rather than above the true value.

Work of Ascent.

In addition to the work which the subject performed of lifting the body-weight to the elevation produced by the grade of the treadmill, ordinarily considered as the only *positive* work done in grade walking, we must also take into account the work which was done (theoretically, at least) in lifting the body a few centimeters at each step in the rise and fall of the body due to the step-lift. That the work of grade-lift is positive and, in the transportation of a superimposed load up a road, may be of economic significance, must not obliterate the fact that physiologically, if the body, or indeed a superimposed load, is lifted a few centimeters during each step, positive work is being accomplished, uneconomical though it may be. The sum of the work due to the step-lift and that due to the grade-lift represents what may therefore be designated as the "work of ascent." From the step-lift as actually measured and the weight of the body, the work performed as a result of the step-lift has been computed and is recorded in column *h* of tables 52 to 55. The "work of ascent" is given in column *i* of the same tables.

In considering the work done during grade walking, we may see from previous discussion that, owing to the uncertainty as to the actual amount of work due to the step-lift, the exact apportionment of the total work between that due to the elevation of the body in the grade-lift and that due to the step-lift is difficult. Doubtless a more subtle analysis of the mechanics of locomotion in the line of the particularly ingenious method of Braune and Fischer,[1] possibly, by means of specially illuminated and figured backgrounds, and the ultra-rapid motion-picture camera, may clarify the situation. Since this may not be made at the present time, and it is desirable to present a hitherto neglected factor in the computation of the efficiency of the body in grade walking, we have assumed that, as a result of the experiments carried out as this report was being written and the considerations set forth on pages 243 to 244, the measurements of the step-lift obtained in this research during grade walking included none of the elevation due to the grade-lift component, and they thus represent the true step-lift. The computations of the work due to this factor which have been made from them may thus be considered as giving the true results.

---

[1] Braune and Fischer, Abhandl. d. math.-phys. Klasse d. Königl. Sächsischen Gesellsch. d. Wissensch., Leipsic, 1895, **21**, p. 153.

Efficiency in Grade Walking.

Efficiency in Work Due to Grade-Lift.

The efficiency with which the work of grade walking was done has been computed from the increment in the heat-output and the kilogrammeters of work performed due to grade-lift, the value of 426.6 kg. m. being used as the mechanical equivalent of 1 calorie.[1] In calculating the percentages, 2.34 gram-calories is taken as the heat equivalent of 1 kg. m. Since the heat values here used are increments above the standing and horizontal-walking requirements, the results represent "net" efficiencies.[2]

A study of these efficiencies in relation to the work performed in grade-lift is of physiological importance. (See column *q* of tables 52 to 55, and column *o* of table 56.) For A. J. O. and W. K., with a 3.6 per cent grade, and E. D. B. with a 5 per cent grade, the efficiencies are all high (approximately 40 per cent). The amounts of work done on these low grades were 172 kg. m. for A. J. O., and under 150 kg. m. for W. K. and, in most cases, for E. D. B. This amount of work is equivalent to approximately one-third of a calorie as compared with the total heat measured of 3 to 4 calories, from which total must be deducted the standing and horizontal-walking values. An error of 0.1 calorie in estimating these values would be a very appreciable amount of the one-third calorie attributable to the work. With these grades the horizontal-walking factor was determined on each day for W. K. and E. D. B. (except for one day in April) and the standing value was the average, with E. D. B., of 23 determinations, with a maximum difference of 0.13 calorie and a maximum deviation from the average of ±0.07 calorie. The difference between the average standing value of 1.10 calories taken for W. K. and the two standing values nearest the date on which he walked with a 3.6 per cent grade differ by only 0.01 and 0.05 calorie. These variations are small, and while they might account for the irregularities in the efficiencies for the different days, they would not account for the constant high efficiencies for these low grades. We are inclined to the opinion that the subject walking on a low grade and performing less than 200 kg. m. of work did so at an efficiency in the neighborhood of 40 per cent. With 250 kg. m. of work and upward, the efficiency for all the subjects is seen to approach 30 per cent.

The effect of the speed on the efficiency with which the work was done may be found from table 56, in which the figures indicate a decreasing efficiency with increasing speed for a definite grade, which naturally results in an increased amount of work. To compare more directly the effect on the efficiency of the work performed, the average efficiency for both W. K. and E. D. B. with increasing amounts of work is given in table 69. These average values are a composite for different grades and speeds and show in each case that, as the work increases, the efficiency diminishes.

---

[1] Armsby, Principles of animal nutrition, New York, 2d ed., 1906, p. 233. A so-called "best" value of 426.7 is reported in the Smithsonian Physical Tables, Washington, 1920, table 212, p. 197. Our computations were made previous to the publication of this edition by means of the slightly lower figure of 426.6.

[2] We have not considered "gross" efficiency in this discussion. Obviously all the data for its computation are readily found in the several tables.

TABLE 69.—*Relation between efficiency in grade-lift and amount of work performed in grade walking by W. K. and E. D. B.*

Kg. m. of grade lift.	Efficiency.	
	W. K.	E. D. B.
	p. ct.	*p. ct.*
400 to 500	28.6	32.7
500 to 600	26.2	32.5
600 to 700	26.2	31.7
800 to 1,000	25.8	30.0
1,000 to 1,600	....	29.3

When the periods for each day are compared, we find that the efficiency tends to fall as the forenoon progressed, this drop being apparent for all subjects, grades, and speeds. It is believed that this is due to fatigue, for though the subject may not be conscious of it for some hours, the onset of fatigue must be early in the performance of work. It must be admitted, however, that no connection appears between the amount of the decrease in efficiency and the amount of work done. Thus, with E. D. B. in the two periods on February 22, when he did over 1,500 kg. m. of work, there was a decrease in the second period of but 0.5 per cent, while on several days when he performed less than one-third this amount of work the efficiency fell during the forenoon 1 to 2 per cent. It is perfectly possible that the subject's physical condition played a part here which obscures the comparison.

The average efficiencies of these five subjects as given in table 70 is 33.4 per cent; if we exclude A. J. O., with whom there was but one experiment with a low grade, we find the average to be 31.3 per cent. The lowest average efficiency was with W. K. at 29.4 per cent, and the highest with E. D. B. at 33.7 per cent. The results for H. R. R. are, we confess, surprising. From our observation, which was influenced, no doubt, by the fact that this subject practically collapsed after the sixth period on May 1, while performing but 550 kg. m. of work, we expected much lower efficiencies from him than from the others, and yet his average value of 31.1 per cent is in accord with that of T. H. H. and of W. K. It should also be mentioned that in the last period of May 1, just before he succumbed, the efficiency for H. R. R. was not different from that in the three preceding periods. The efficiencies of these men (omitting A. J. O.) lie so close together that no statement may be made regarding superiority. The fact that E. D. B. stands somewhat above the others may be accounted for by the relatively large number of experiments in which there was a small amount of work. As has been stated, in all such experiments the subjects show a higher efficiency than in those with a greater amount of work. There is hardly sufficient ground in the small difference for E. D. B. to suppose that as an individual he was any more efficient than the other four men.

TABLE 70.—*Efficiency of subjects in grade-walking experiments.*

Subject.	No. of experiments.	Efficiency in grade-lift.		
		Minimum.	Maximum.	Average.
		p. ct.	*p. ct.*	*p. ct.*
A. J. O.	1	....	....	41.8
H. R. R.	6	29.3	32.5	31.1
T. H. H.	8	28.9	34.4	30.8
W. K.	48	25.2	44.2	29.4
E. D. B.	79	27.0	48.7	33.7
Average	....	....	....	33.4
Average omitting A. J. O.	....	....	....	31.3

Many reports on the mechanical efficiency of men doing various forms of work have been published. One of the earliest was that of Edward Smith,[1] who used a tread-wheel and from whose results Helmholtz[2] computed a gross efficiency of 20 per cent.

A large amount of work on the energy exchange in man during walking has been done by both Zuntz and Durig and their associates, to which reference has already been made. (See pp. 8 to 13.) In the summary of the results[3] given in table 71 and obtained with men walking on a treadmill at grades of 12.68 to 36.2 per cent, the net efficiencies range from 25.7 to 46.5 per cent, with a distinct tendency to approach 33 per cent. This is in close accord with our results.

The efficiencies of men performing other kinds of work, such as using a wheel and brake, lifting weights, and riding a stationary bicycle, have been studied by a number of investigators, and their results have been discussed by Benedict and Cathcart.[4] In many cases there is no clear distinction between the "gross" and "net" efficiency, and in several studies only the carbon-dioxide output is determined. Naturally, these results show considerable variation, depending upon the subject, the form of work, and not infrequently upon the method of computation employed. It may be said that these net efficiencies are, as a rule, lower than for walking and are nearer 27 to 28 per cent than they are to 33 per cent. The first studies made with the bicycle ergometer were carried out by Atwater and Benedict[1] and showed net efficiencies of 19.6 per cent as an average of 14 experiments. Later experiments reported by Benedict and Carpenter[2] showed efficiencies of 20 to 23 per cent, and other experiments by Benedict and Cathcart[3] with a professional bicyclist, M. A. M., gave efficiencies approaching 33 per cent.

---

[1] Smith, Edward, Phil. Trans., 1859, **149**, p. 681.

[2] Helmholtz, Proc. Roy. Inst., 1861, **3**, p. 347.

[3] Drawn from Durig, Denkschr. d. math. natur. Klasse d. kaiserl. Akad. d. Wissensch., 1909, **86**, p. 299.

[4] Benedict and Cathcart, Carnegie Inst. Wash. Pub. No. 187, 1913, p. 101.

TABLE 71.—*Efficiency of men in treadmill walking with different grades, as summarized by Durig.*[1] (*Values per minute.*)

Grade in per cent.	Grade-lift.	Heat-output per kg. m. of grade-lift.	Efficiency.	Experimenters.
	kg. m.	*gm.-cal.*	*p. ct.*	
31.0	602.9	8.68	26.9	Schumburg and Zuntz.
	459.6	8.90	26.3	
	594.4	9.11	25.7	
	691.6	8.89	26.3	
	(620.0)	(6.98)	33.5	
31.0	774.3	8.58	27.3	
	784.3	8.14	28.7	
	810.5	8.50	25.7	
	757.7	8.21	28.5	
	763.1	8.11	....	
22.9	555.0	6.82	34.3	A. and J. Loewy and L. Zuntz.
30.4	677.0	6.84	34.3	
36.2	812.0	6.53	35.8	
23.0	....	6.430	36.4	Frentzel and Reach.
	....	6.664	35.1	
12.68	680.2	5.488	42.7	Zuntz, Loewy, Müller, and Caspari.
12.68	489.6	5.402	43.3	
12.68	359.8	6.064	38.6	
26.2	795.1	7.991	29.3	
12.68	369.6	7.223	32.1	
12.68	580.5	7.057	33.2	
18.24	570.8	5.033	46.5	
21.6	830.3	6.73	34.9	Durig.[2]
14.7	695.3	6.87	34.1	

[1] Durig, Denkschr. d. math.-natur. Klasse d. kaiserl. Akad. d. Wissensch., 1909, 86, p. 299.
[2] *Ibid.*, p. 341. An apparent typographical error in the average for the heat-output per kilogrammeter of grade-lift for 21.6 per cent grade has been corrected here.

It may be stated, therefore, that the human machine can accomplish various forms of muscular work at a net efficiency greater than 25 per cent, and that grade walking is the most efficient of the various forms of exercise thus far studied, the efficiency for this probably being 33 or more per cent.

---

[1] Atwater and Benedict, U. S. Dept. Agr.. Office Exp. Sta. Bull. No. 136, 1903, p. 190.
[2] Benedict and Carpenter, U. S. Dept. Agr., Office Exp. Sta. Bull. 208, 1909.
[3] Benedict and Cathcart, Carnegie Inst. Wash. Pub. No. 187, 1913, p. 121.

EFFICIENCY IN WORK OF ASCENT.

The total heat-output during grade walking is made up of a number of factors: first, the basal requirement for standing; second, the superimposed work of forward progression, including the step-lift; and third, the actual elevation of the body as a result of the grade. A computation of the proportion of energy ascribable to the actual lifting of the body, such as is done not only in the grade-lift but in the superimposed step-lift, necessitates the deduction of certain basal values. Of these, obviously that for the standing metabolism would be one, but the deduction of the standing metabolism only does not allow for the energy of forward progression. Ordinarily, the entire energy due to horizontal walking is deducted before the efficiency for grade walking is computed, but this is illogical, since the energy required for forward progression includes a not inconsiderable proportion rightly attributable to the elevation of the body in the step-lift, which is an integral factor in grade walking. When the increments in the total heat of horizontal walking over the requirement for the standing position are compared with the computed heat ascribable to the work done by the body in the step-lift, it is seen that the heat-output due to this secondary elevation of the body was an appreciable percentage of the total increase in energy and varied with the speed at which the man walked. (See table 43, p. 159.) Consequently, in computing the efficiency for the work of ascent, a deduction should be made from the total heat-production of a certain proportion of the energy required for horizontal walking at a similar rate, this deduction depending upon the speed of walking.

It has seemed unwise to use all of our data in computing the efficiency for the work of ascent, inasmuch as the method of computation is at best based upon problematical assumptions. We have, however, computed the efficiency for a number of typical days with E. D. B. at varying grades and speeds. These results are recorded in table 72. This table is best considered in relation to table 55 (p. 209), the data in columns *a* to *e* being drawn from that table. The work of the total lift of the body, that is, the work of ascent, which includes both the grade-lift and the step-lift in grade walking, is recorded in column *c*. The total increment in the heat over standing in column *d* represents the total heat measured during the grade walking, less the standing requirement. The total heat due to the horizontal component is recorded in column *e* and, as originally recorded in table 55, was obtained by first multiplying the weight of the body by the horizontal component of the distance walked and then multiplying the result by the factor for the energy required for each horizontal kilogrammeter (column *n* of table 55).

The first important new step is the computation of the heat due to the horizontal component, less that fraction due to the step-lift in walking on a level. From table 43, the percentage of the increase in heat due to the step-lift in horizontal walking may be computed for E. D. B. for the average speeds. These percentages, although made up of somewhat widely varying individual values, are as follows: For 45 meters, 9 per cent; for 55 meters, 11 per cent; for 65 meters, 15 per cent; for 72 meters, 16 per cent; and for 77 meters, 18 per cent. The proportions of the total heat for the horizontal component to be deducted from the total heat over standing are, therefore, for a speed of 45 meters,

TABLE 72.—*Efficiency for work of ascent of E. D. B.*[1] (*Average values per minute.*)

Date.	(*a*) Grade.	(*b*) Distance walked.	(*c*) Work of total lift (work of ascent).	(*d*) Total increment in heat over standing.	Heat due to horizontal component.			Heat due to work of ascent.		(*j*) Efficiency for work of ascent. $\frac{2.34 \times 100}{i}$
					(*e*) Total.	(*f*) Proportion due to step-lift.	(*g*) Less amount due to step-lift. $\frac{e \times (100-f)}{100}$	(*h*) Total. $(d-g)$	(*i*) Per kg.m. of work of ascent. $(h \div c)$	
1915–16.	*p. ct.*	*meters.*	*kg. m.*	*cals.*	*cals.*	*p. ct.*	*cals.*	*cals.*	*gm.-cals.*	*p. ct.*
Nov. 4	5.0	48.2	198.1	2.08	1.25	9	1.14	0.94	4.7	49.8
6	5.0	48.2	200.7	1.98	1.23		1.12	.86	4.3	54.4
17	10.3	48.0	398.9	3.20	1.27		1.16	2.04	5.1	45.9
Dec. 7	15.0	46.4	555.5	4.09	1.20		1.09	3.00	5.4	43.3
Feb. 2	25.0	46.5	976.4	7.00	1.27		1.16	5.84	6.0	39.0
8	30.0	46.0	1,104.8	7.34	1.22		1.11	6.23	5.6	41.8
18	40.0	49.5	1,526.6	10.44	1.26		1.15	9.29	6.1	38.4
Nov. 9	5.0	54.8	243.3	2.24	1.35	11	1.20	1.04	4.3	54.4
10	5.0	55.4	244.7	2.19	1.40		1.25	.94	3.8	61.6
23	10.0	57.2	484.1	3.76	1.39		1.24	2.52	5.2	45.0
Dec. 8	15.0	58.3	702.2	5.28	1.47		1.31	3.97	5.7	41.1
17	20.0	53.4	809.2	5.55	1.29		1.15	4.40	5.4	43.3
Feb. 3	25.0	52.6	1,036.6	7.63	1.42		1.26	6.37	6.1	38.4
9	30.0	53.6	1,291.4	8.80	1.42		1.26	7.63	5.9	39.7
16	35.0	57.6	1,568.3	11.10	1.49		1.33	9.77	6.2	37.7
21	40.0	57.1	1,774.1	12.50	1.46		1.30	11.20	6.3	37.1
Nov. 11	5.0	66.0	299.6	2.72	1.76	15	1.50	1.22	4.1	55.8
26	10.0	66.5	586.8	4.52	1.69		1.44	3.08	5.2	45.0
Dec. 13	15.0	66.8	798.0	5.84	1.61		1.37	4.47	5.6	41.8
20	20.0	66.4	1,052.9	7.14	1.64		1.39	5.75	5.3	44.2
Jan. 5	25.0	69.3	1,326.5	9.90	1.78		1.51	8.39	6.3	37.1
Feb. 11	30.0	69.5	1,676.6	11.81	1.84		1.56	10.25	6.1	38.4
22	40.0	65.2	1,996.5	14.45	1.66		1.41	13.04	6.5	36.0
Nov. 13	5.0	74.1	375.3	3.16	1.97	16	1.65	1.51	4.0	58.5
Dec. 3	10.0	70.5	650.8	4.87	1.85		1.55	3.32	5.1	45.9
14	15.0	73.4	909.5	6.54	1.92		1.61	4.93	5.4	43.3
21	20.0	70.3	1,078.8	7.76	1.72		1.44	6.32	5.9	39.7
Feb. 5	25.0	71.0	1,429.1	10.24	1.91		1.60	8.64	6.0	39.0
12	30.0	71.5	1,710.6	11.86	1.91		1.60	10.26	6.0	39.0
Nov. 30	10.0	78.5	704.1	5.62	2.15	18	1.76	3.86	5.5	42.5
Dec. 16	15.0	81.3	975.5	7.29	2.09		1.71	5.58	5.7	41.1
31	20.0	80.1	1,205.4	9.94	2.22		1.82	8.12	6.7	34.9
Feb. 7	25.0	75.9	1,565.6	11.42	2.15		1.76	9.66	6.2	37.7

[1] See table 55 (p. 209) for data in columns *a* to *e*.

100 per cent less 9 per cent, or 91 per cent; for 55 meters, 89 per cent; for 65 meters, 85 per cent; for 72 meters, 84 per cent; and for 77 meters, 82 per cent. The values to be deducted for the heat due to the horizontal component, as thus computed, are given in column *g*. The heat due to the work of ascent may then be calculated by deducting from the total increment in heat over standing (column *d*) the heat due to the horizontal component corrected for that due to the step-lift (column *g*). The resulting values are recorded in column *h*, and represent the increase in heat actually ascribable to the work of ascent. Dividing these values by the kilogrammeters of work of ascent (column *c*), we obtain the increment in heat per kilogrammeter of work of ascent. This is best expressed in gram-calories as recorded in column *i*. From these latter values the efficiency of the body for the total work of ascent is readily computed by using 2.34 gram-calories as the heat equivalent of 1 kg. m. These percentages are given in column *j*, and represent net efficiencies.

From the general consideration of the efficiency of the body as computed on the basis of grade-lift, it was found that these values represented an average for all of the subjects not far from 33 per cent. (See table 70, p. 251.) By this new method of computation, which ascribes a larger amount of work to the body, since the step-lift is superimposed upon the grade-lift, we find that for this subject (E. D. B.) the percentage of efficiency is larger, in some instances actually reaching 50 to 60 per cent, with a maximum on November 10 of 61.6 per cent. Under the separate groupings for the different speeds, the experiments have been arranged in the order of increasing grade, running for the most part from 5 to 40 per cent, except with the two higher-speed groups when the steepest grades were but 30 and 25 per cent, respectively. An inspection of the figures for these efficiencies in column *j* shows that, in general, the percentages fall as the grade increases, i. e., within each speed group there is a distinct tendency for the efficiency to be somewhat lower with the higher grades.

It is more than likely that the difficulty in computing the ratio between the fraction of the energy expended for the grade-lift and that expended for the standing and horizontal walking when an extremely low grade was employed may in part account for the high values here found, a point which has been touched upon in the earlier discussion of the grade-lift measurements. With constant grade, but varying speeds, the percentage efficiency for the 10 per cent grade remains practically constant throughout the entire series at 45 per cent; with the 15 per cent grade they likewise are reasonably constant; with a 30 per cent grade a slight decrease in the efficiency is apparent, which may also be seen with the 40 per cent grade.

The whole problem of computing the efficiency on this basis may reasonably be challenged on the grounds that not only is the value of the step-lift uncertain, but also we are not dealing here with "effective" external muscular work. The transportation of the body up-grade or the transportation of a superimposed load, such as was done in many of Durig's experiments, may definitely be classed as "effective" muscular work. The step-lift, both with the body and with the superimposed load, can not be considered in the ordinary process of walking as effective external work. Nevertheless we believe that this treatment has distinct physiological interest in the strong suggestion that attention to the type of gait, particularly in minimizing the step-lift, may not be without definite economic importance in considering the human body as an efficient machine.

Effect of Lameness upon the Efficiency of E. D. B.

As has been stated elsewhere, E. D. B. developed a lameness in the instep of his right foot early in January. As a result, the experiments with him were discontinued for a period of three weeks, beginning with January 10. On inquiry it developed that he had been conscious of some pain in the instep for a number of days, although he had made no complaint. The question accordingly arose whether the lameness was of sufficient moment to vitiate the results of the standing and grade-walking experiments on January 3, 4, and 5. The metabolism data obtained on these days have accordingly been collected in table 73. For comparison, the data are included for the standing experiment of December 31 and the grade-walking experiment of January 1 before the lameness developed, and for the grade-walking experiment of February 4, when the lameness had been cured by three weeks of rest.

As would be expected, the metabolism during standing was evidently not affected, as the data for January 3, 4, and 5 agree well with those obtained on December 31, before the lameness developed. In the grade-walking experiments of January 3 and 4, the values for the energy cost per kilogrammeter and the percentage efficiencies show slight changes from corresponding data obtained on January 1 and February 4; nevertheless the differences are so slight that they may be considered as within the limits of experimental error. The efficiency for the other day (January 5) agrees well with those of January 1 and February 4. There is therefore no reason to discredit the values reported for these three days.

On January 10, when the subject began walking preliminary to the experimental period, the pain in his instep was so severe that it was necessary to end the experiment. The standing data for this day have not been included in any of the tables previously discussed, but are given in table 73. These values show a very slight increase in the carbon-dioxide production and heat-output. Although it was noted in the protocols of the experiment that the subject "stood mostly on the left foot" and "favored his right leg," the difference in the metabolism values is too small to indicate that the subject was standing at a disadvantage. Zuntz and Schumburg[1] report that when one of their subjects walked with a lame foot, the metabolism increased 9.2 per cent. This might well have occurred with E. D. B. on January 10 had we insisted on continuing the experiment, as his lameness caused him great discomfort in walking. On January 3, 4, and 5, the lameness was apparently of too little account to affect his efficiency.

Table 73.—*Effect of slight lameness upon the metabolism and efficiency of E. D. B. (Values per minute.)*

Date and conditions.	Carbon dioxide.	Oxygen.	Respiratory quotient.	Heat-output.
Standing:				
No lameness:	*c. c.*	*c. c.*		*cals.*
Dec. 31..........	211	257	0.82	1.24
Slightly lame:				
Jan. 3..........	210	250	.84	1.21
4..........	212	244	.87	1.19
5..........	206	253	.81	1.22
Too lame to walk grade:				
Jan. 10..........	224	251	.89	1.23

Date and conditions.	Work due to grade-lift.	Carbon dioxide.	Oxygen.	Respiratory quotient.	Heat-output per kg. m. of grade-lift.	Efficiency.
Grade walking:						
No lameness:	*kg. m.*	*c. c.*	*c. c.*		*gm.-cals.*	*p. ct.*
Jan. 1..........	935	2,010	2,272	0.88	8.3	28.2
Feb. 4..........	932	1,903	2,084	.91	8.0	29.2
Slightly lame:						
Jan. 3..........	628	1,183	1,451	.82	7.5	31.2
4..........	872	1,723	1,965	.88	7.8	30.0
5..........	993	2,054	2,252	.91	8.2	28.5

Physiological Effects of Grade Walking.

Respiration-Rate During Grade Walking.

The respiration-rates during the experiments with grade walking (see tables 13 to 16, pp. 69 to 78) tended to increase slightly in each period as the forenoon progressed. This increase, in a few instances, was as large as 5 respirations per minute, but in the majority of cases it was only 1 or 2 respirations per minute over that of the first walking period. The increase between periods does not appear to be associated with the amount of work which the subject was performing, and the differences were no greater when the larger amounts of work were done.

The average respiration-rates are also given in table 56 (p. 221), in which the experimental data have been grouped according to the grade and speed of walking, and not according to the sequence of the experiments. As a rule, the changes in the rates progressed gradually and uniformly with the increase in the speed and the amount of work performed. The maximum rate was found with the maximum work with each subject, although this is not true of the minimum amount of work. The difference in the respiration-rates for the different subjects is noticeable. At the medium speed of 60 to 65 meters per minute with a 10 per cent grade, T. H. H. had a low rate of 17.9 as compared with W. K.'s rate of 26.1; E. D. B. had a rate of 26.7 when walking on a 25 per cent grade at 70 to 75 meters per minute as compared with W. K.'s rate of 40 under similar conditions.

---

[1] Zuntz and Schumburg, Physiologie des Marsches, Berlin, 1901, p. 265.

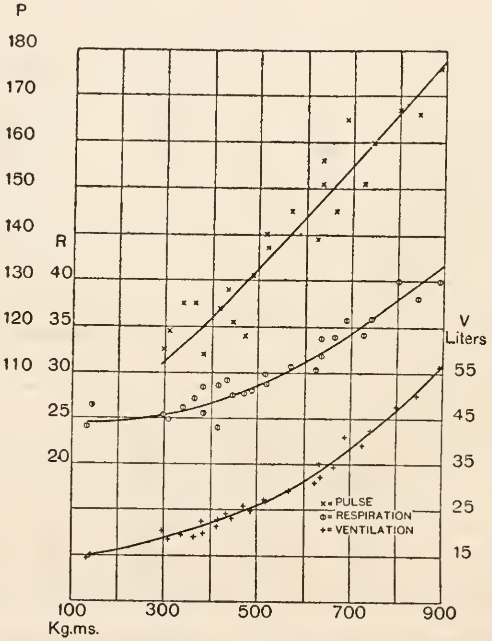

FIG. 28.—Pulse-rate, respiration-rate, and pulmonary ventilation of W. K. during grade walking, referred to kilogrammeters of work. (Values per minute from table 56.)

The curves for the average respiration-rates for W. K. and E. D. B. in table 56 have been plotted and presented in figures 28 and 29. The curve for E. D. B. shows a uniform rate of increase, but that for W. K. indicates a greater rate of increase beyond 300 kg. m. From these curves an estimate has been made of the respiration-rates per minute for increasing amounts of work. (See second column of tables 74 and 75.) From these values have been calculated the total and percentage increases in the respiration-rate over the standing requirement, and also the increments per 100 kg. m. as the unit of work done. The rapid increase in the respiration-rate of W. K. as the work increased manifests itself here in an increase over the standing requirement per 100 kg. m. of work, while for E. D. B. the increase per 100 kg. m. diminished as the amount of work became larger and reached constancy at about 800 to 900 kg. m. The percentage increase over the standing value for W. K. ranged from 16 to nearly 100 per cent, with an increase per 100 kg. m. of 7 to 11 per cent. With E. D. B. the increase was as high as 40 per cent for the first 100 kg. m., but it fell rapidly and above 700 kg. m. the increase per 100 kg. m. was constant at a level of 7 and 8 per cent.

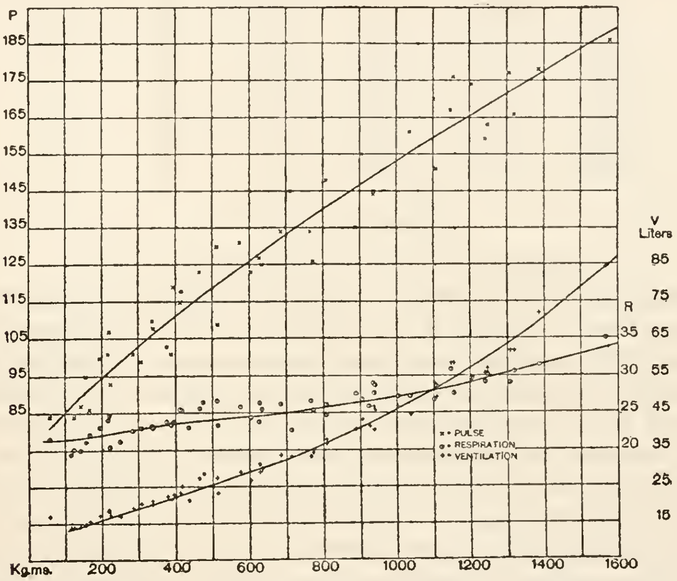

FIG. 29.—Pulse-rate, respiration-rate, and pulmonary ventilation of E. D. B. during grade walking, referred to kilogrammeters of work. (Values per minute from table 56.)

TABLE 74.—*Respiration-rate of W. K. with increasing amounts of work in grade-walking experiments without food. (Values per minute.)*[1]

Kg. m. of work.	Respiration-rate during grade walking.	Increase over standing rate (21.1)		Percentage increase over standing rate.	
		Total.	Per 100 kg. m.	Total.	Per 100 kg. m.
200	24.5	3.4	1.7	16	8
300	25.3	4.2	1.4	20	7
400	26.8	5.7	1.4	27	7
500	28.6	7.5	1.5	36	7
600	31.3	10.2	1.7	48	8
700	34.3	13.2	1.9	63	9
800	38.0	16.9	2.1	80	10
900	41.7	20.6	2.2	98	11

[1] Based upon figure 28.

TABLE 75.—*Respiration-rate of E. D. B. with increasing amounts of work in grade-walking experiments without food. (Values per minute.)*[1]

Kg. m. of work.	Respiration-rate during grade walking.	Increase over standing rate (15.4)		Percentage increase over standing rate.	
		Total.	Per 100 kg. m.	Total.	Per 100 kg. m.
100	21.5	6.1	6.1	40	40
200	22.0	6.6	3.3	43	22
300	23.0	7.6	2.5	49	17
400	23.6	8.2	2.1	53	13
500	24.1	8.7	1.7	56	11
600	24.5	9.1	1.5	59	10
700	25.0	9.6	1.4	62	9
800	25.7	10.3	1.3	67	8
900	26.5	11.1	1.2	72	8
1,000	27.5	12.1	1.2	79	8
1,100	28.0	12.6	1.1	82	7
1,200	29.1	13.7	1.1	89	7
1,300	30.5	15.1	1.2	98	8
1,400	31.6	16.2	1.2	105	8
1,500	32.8	17.4	1.2	113	8

[1] Based upon figure 29.

PULMONARY VENTILATION DURING GRADE WALKING.

The data for the pulmonary ventilation during the grade-walking experiments are also given in detail in tables 13 to 16, pages 69 to 78, from which it is seen that though on some days the ventilation increased from period to period, this increase was not so pronounced and appears to be much more nearly uniform and less influenced by continued exercise than was the case with the respiration-rate. Naturally the volume varied with the individual subjects and primarily with the amount of work that was performed. The variations in the rate of increase due to increases in grade and speed are best seen in the group averages in table 56, from which it is evident that, almost without exception, the average ventilation increased with each increase in speed for the several grades or each increase in grade for a uniform speed. The figures thus give some indication of what may be required by a person when doing a definite amount of muscular work. The significance of these figures in the designing of suitable gas-masks is obvious. In general, it may be said that 17 to 21 liters per minute represents the average rate for a moderate speed of 50 to 60 meters per minute (approximately 2 miles an hour) when the subject is walking on a 10 per cent grade, or when he is doing approximately 335 kg. m. of work. The amount of ventilation increased as the grade and speed increased to a maximum of 85 liters per minute, as in the case of E. D. B. with 1,569 kg. m. of work.

As previously stated (see p. 192), the use of the mouthpiece in these grade-walking experiments did not apparently affect the normality of the results obtained for the respiration-rate and the pulmonary ventilation, notwithstanding the quickened respiration and greater ventilation as a consequence of the severe exercise.

The ventilation-rates for W. K. and E. D. B. have been plotted and are included with the respiration curves in figures 28 and 29, based on kilogrammeters of work performed. In these two curves the total ventilations of W. K. and E. D. B. are practically the same for like amounts of work up to 500 kg. m.; beyond this point the total ventilation of W. K. exceeds that of E. D. B. for similar amounts of work. From the curves in figures 28 and 29, an estimate has been made of the ventilation requirements for increasing amounts of work. (See tables 76 and 77.) From these values are found the total and percentage in-

TABLE 76.—*Pulmonary ventilation of W. K. with increasing amounts of work in grade-walking experiments without food. (Values per minute.)*[1]

Kg. m. of work.	Pulmonary ventilation (reduced).	Increase over standing rate (6.5 liters).		Percentage increase over standing rate.	
		Total.	Per 100 kg. m.	Total.	Per 100 kg. m.
	liters.	*liters.*	*liters.*		
200	16	9.5	4.8	146	73
300	19	12.5	4.2	192	64
400	22	15.5	3.9	238	60
500	26	19.5	3.9	300	60
600	31	24.5	4.1	377	63
700	39	32.5	4.6	500	71
800	47	40.5	5.1	623	78
900	57	50.5	5.6	777	86

[1] Based upon figure 28.

TABLE 77.—*Pulmonary ventilation of E. D. B. with increasing amounts of work in grade-walking experiments without food. (Values per minute.)*[1]

Kg. m. of work.	Pulmonary ventilation (reduced).	Increase over standing rate (9.1 liters).		Percentage increase over standing rate.	
		Total.	Per 100 kg. m.	Total.	Per 100 kg. m.
	liters.	*liters.*	*liters.*		
200	16	6.9	3.5	76	38
300	19	9.9	3.3	109	36
400	22	12.9	3.2	142	36
500	26	16.9	3.4	186	37
600	29	19.9	3.3	219	37
700	32	22.9	3.3	252	36
800	37	27.9	3.5	307	38
900	41	31.9	3.5	351	39
1,000	46	36.9	3.7	405	41
1,100	51	41.9	3.8	460	42
1,200	57	47.9	4.0	526	44
1,300	64	54.9	4.2	603	46
1,400	71	61.9	4.4	680	49
1,500	79	69.9	4.7	768	51
1,600	87	77.9	4.9	857	54

[1] Based on figure 29.

creases over the standing requirements as well as the increase over the standing requirements per 100 kg. m. of work performed. These figures show an increment over the standing requirement of 777 per cent for W. K. for 900 kg. m. and 857 per cent for E. D. B. for 1,600 kg. m. of work. For a unit amount of work of 100 kg. m., however, there is a gradual decrease up to 600 kg. m. for W. K. and to 800 kg. m. for E. D. B. Beyond these points the ventilation per 100 kg. m. increased in each case, reaching 5.6 liters for W. K. as compared with 3.5 liters for E. D. B. at 900 kg. m.

Pulse-Rate During Grade Walking.

The pulse-rates for a definite grade and speed of walking are influenced in these experiments by several factors, but chiefly by (1) the daily rate for the standing position, which, as seen from tables 3 to 7, shows variation from day to day; and (2) the variation in the speed at which the subject walked, due to our inability to control exactly the speed of the treadmill. Furthermore, it is noticeable in the data in tables 13 to 16 that almost without exception the average pulse-rate increased with each succeeding period. As has been stated, the pulse-rates for the individual periods represent an average, in most cases, of 3 one-minute records. This increase from period to period may, in some cases, be due to the gradual alteration in the speed at which the subject walked; but since there are numerous instances when the pulse-rate increased though the speed decreased, the increment in pulse-rate is more likely due to fatigue with the continuation of the work. The increase from period to period is seen to have a variation of from 2 to 3 beats per minute to as high as 15 beats, with a total accumulated increase in the pulse-rate during a forenoon in a few instances of as much as 30 beats a minute while the same work is being performed. This rise in the pulse-rate, due to the cumulative effect of the exercise, makes the values given as the average for the day misleading, for an average made up of 5 or 6 continuous walking periods would be much higher than when but half that number of walking periods are included in the experiment. Furthermore, any failure to secure the record of the pulse-rate for a period tends to change the average value reported for the day.

In spite of these difficulties and of the recognized objection to these so-called daily averages, it is believed that the errors that are present are minimized to a considerable extent by the number of the experiments and that the general picture is correct. An inspection of the daily averages in tables 13 to 16 shows an approximate pulse-rate for an approximate amount of work performed. This is more apparent in table 56, in which the values are not averages for the individual days, but for the periods falling within 5-meter speed groups with different grades.

The high pulse-rate of H. R. R. in most of the standing and horizontal-walking experiments persists, also, in the grade experiments, in which a rate of 140 was found with the subject walking on a 10 per cent grade at a speed of 60 to 65 meters per minute (about 2.5 miles an hour), as compared with a rate of 125 and 103 for W. K. and E. D. B., respectively, under similar conditions. (See table 56.)

T. H. H. shows the exceptional behavior of a falling pulse with increase in the speed for the single grade used in his experiments. This is due, in part, to the considerable number of periods on April 6 and 7, when all of the period data for the lowest speed (55 to 60 meters per minute) were obtained. Out of the 9 periods composing the average for a speed of 55 to 60 meters a minute, the 3 highest were the last records of a continuous forenoon performance on April 7 of 6 periods. The average pulse-rate for this speed was therefore high on account of the cumulative effect of the work on these days. However, this will not entirely account for the fact that this subject had a decreasing pulse-rate with increasing work. On April 15, when he performed his largest amount of work, his pulse-rate was distinctly lower than on the previous days. A week intervened between this experiment and the preceding one, but we have no record that his physical condition was different in this experiment from that in any other. Evidently the experiments with T. H. H. were not continued long enough to determine his representative pulse-rate in the performance of a moderate amount of exercise.

W. K. and E. D. B. offer more data for comparison. These values indicate that, with occasional exceptions, the pulse-rate progressed with the speed for each grade. The increase in the pulse-rate in relation to the amount of work performed is depicted in the curves for these subjects in figures 28 and 29,[1] which are based upon the averages in table 56. They indicate a practically uniform increase with increase in the amount of work done. The curve for W. K. ascends more sharply than that for E. D. B., the average pulse-rate increasing from 115 to 176 beats for an increase from 298 to 891 kg. m., or approximately one beat for every 9.7 kg. m. increase in work, while the average pulse-rate of E. D. B. increased from 84 to 186 beats for an increase in work from 59 to 1,569 kg. m., or an increase of one beat for every 14.8 kg. m. increase in work. If these values are referred to the average basal value found in the standing experiments (79 for W. K. and 78 for E. D. B.), the increase for the maximum amount of work is found to be 123 per cent for 891 kg. m. with W. K. and 138 per cent for 1,569 kg. m. with E. D. B. This would correspond to an increase of approximately 7 kg. m. for every 1 per cent of increase in the pulse-rate for W. K. and 11 kg. m. for E. D. B.

---

[1] All of the curves in these two figures represent averages of estimates drawn independently by three members of the Laboratory staff.

Comparing these increases in the pulse-rate with the increases in the oxygen consumption for like amounts of work, we find that with W. K., when he was doing the maximum amount of 891 kg. m. of work, the increase in the oxygen consumption over his standing requirement was 818 per cent, and with E. D. B. for 1,569 kg. m., the increase was 1,205 per cent. (See table 57, p. 224.) This shows the enormous increase in the oxygen consumption as compared with the increase in the pulse-rate. How this great increase in oxygen consumption is provided for is still undetermined. Certainly, neither the increase in the pulse-rate nor any probable increase in the oxygen-carrying capacity of the blood due to the more complete combination with the hemoglobin can account for it, and an increase in the volume output of the heart, with perhaps a large pulmonary oxidation[1] under these conditions, seems probable.

Table 78.—*Pulse-rate of W. K. with increasing amounts of work in grade-walking experiments without food. (Values per minute.)*[1]

Kg. m. of work.	Pulse-rate.	Increase over standing rate (79).	Percentage increase over standing rate.	
			Total.	Per 100 kg. m.
			p. ct.	*p. ct.*
300	112	33	42	14
400	122	43	54	14
500	133	54	68	14
600	144	65	82	14
700	155	76	96	14
800	166	87	110	14
900	177	98	124	14

[1]Based upon figure 28, p. 258.

From the curves in figures 28 and 29, estimates may be made of the increase in pulse-rate with increasing amounts of work, as was done for the total oxygen consumption, total heat-output, and other factors. These estimates are recorded in tables 78 and 79, together with the increase over the average values for the standing experiments. The percentage increases in the last column of these tables show that with W. K. the pulse-rate increased 14 per cent for each 100 kg. m. of work done over his average pulse-rate of 79 during standing; with E. D. B. the increase over his standing average of 78 was more nearly 10 per cent for each 100 kg. m. The increase in the oxygen consumption on this same basis varied from 139 to 97 per cent for W. K. and from 150 to 77 per cent for E. D. B. (See tables 58 and 59, p. 229.) The approximation to constancy in the percentage increase of the pulse-rate with each 100 kg. m. of work is in marked contrast to the fall in

---

[1] Henderson, Am. Journ. Physiol., 1912-13, **31**, p. 352.

TABLE 79.—*Pulse-rate of E. D. B. with increasing amounts of work in grade-walking experiments without food. (Values per minute.)*[1]

Kg. m. of work.	Pulse-rate.	Increase over standing rate (78).	Percentage increase over standing rate.	
			Total.	Per 100 kg. m.
			p. ct.	*p. ct.*
100	85	7	9	9
200	95	17	22	11
300	103	25	32	11
400	111	33	42	11
500	119	41	53	11
600	126	48	62	10
700	133	55	70	10
800	140	62	80	10
900	147	69	88	10
1,000	153	75	96	10
1,100	159	81	104	9
1,200	165	87	112	9
1,300	171	93	119	9
1,400	177	99	127	9
1,500	184	106	136	9
1,600	189	111	142	9

[1] Based upon figure 29.

the percentage increase over the standing requirement for the oxygen consumption with each 100 kg. m. of work, clearly indicated in tables 58 and 59.

In figures 30 to 32, a few typical curves are given of the pulse-rates of E. D. B. during grade walking with the accompanying changes before and after the exercise. The pulse-rates immediately preceding and following the beginning and end of the exercise will be considered in another section in discussing the transitional periods for changes in

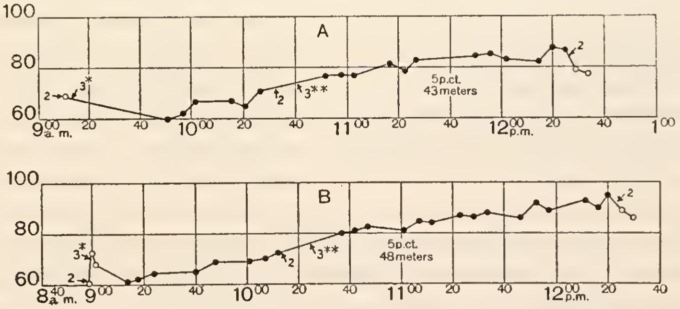

FIG. 30.—Typical pulse curves of E. D. B., with subject standing, walking on a level, and walking on an incline. (Values per minute.)

2, subject standing; 3*, walking on a level; 3**, walking on an incline. Black points, records during experimental periods; open circles, records between periods. Curve A, Nov. 5; B, Nov. 6, 1915.

conditions (pp. 297 to 305). As in similar figures, the number 1 indicates that the subject was sitting, and 2 that he was standing. The time at which the subject began walking is indicated by the figure 3.[1] The points indicated by open circles represent per minute values obtained in the interval between the experimental periods.

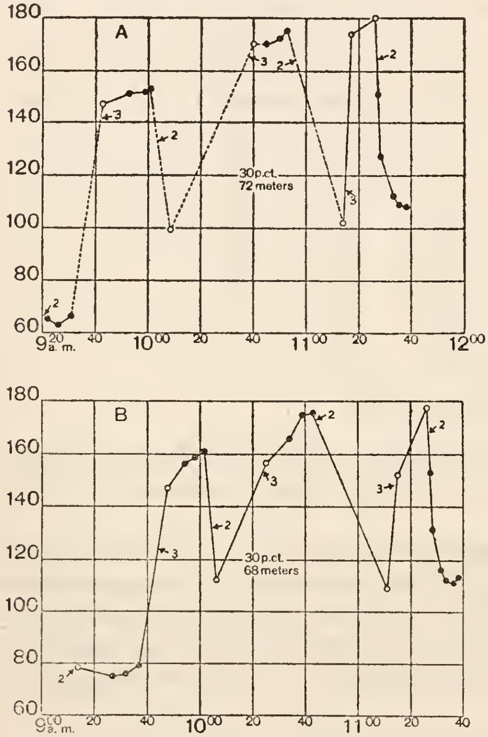

FIG. 31.—Typical pulse curves of E. D. B., with subject standing and walking on an incline. (Values per minute.)

2, subject standing; 3, walking on an incline. Black points, records during experimental periods; open circles, records between periods. Curve A, Feb. 12; B, Feb. 14, 1916.

Curve A in figure 30 gives a picture of the rate when the subject was walking on a level up to $10^h\ 33^m$ a. m., stood until $10^h\ 40^m$ a. m., and thereafter walked on a 5 per cent grade until $12^h\ 27^m$ p. m., when he again stood for a short time. The course of the curve is but little altered by the change to grade walking, and there were no sudden or marked variations in the rate during the forenoon. Curve B in figure 30 is also for an experiment with a 5 per cent grade preceded by walking on a level, but on this day the speed was a little higher. Curve B has the same general appearance as curve A, however, except that the rise due to the walking is somewhat more marked. Both curves indicate a slight fall at the beginning of the walking on a level and the usual fall in the pulse-rate when the grade walking ceased at the end of the experiment. In curve A the pulse-rate after the walking ceased reached more nearly the initial level than in curve B, but as the observations were continued only 7 minutes after the walking ceased, no information could be gained as to how long a period elapsed before the pulse returned to normal. In the curves in figures 31 and 32, showing the rate after severe exercise, the pulse was still above the normal after 5 to 7 minutes, but here again the records were not continued a sufficient length of time to determine whether the pulse-rate returned to the normal value or remained at a higher rate for some hours, as was observed by Benedict and Cathcart.[1]

---

[1] It should be noted that the arrow indicates the *time* of the change and not the pulse-rate. For instance, in fig. 31, curve A makes direct connection between the two readings at $9^h\ 31^m$ and $9^h\ 43^m$ a. m.; the walking began at $9^h\ 42^m$ a. m. If the arrow were taken to indicate the pulse-rate at this time, the rate would appear to be 142. On the contrary, it was probably more nearly 66 to 68, and the curve for the rise due to the activity of walking is actually much steeper than here drawn.

Curve A in figure 31 shows a rise from an average rate of 64 to a rate of 146 when the subject began to walk on a 30 per cent grade. When he stopped walking at the end of the first period, there was an immediate drop of 53 beats. When the walking began again, the pulse-rate rose to 170, with a greater fall at the end of the second period of walking and a still greater rise for the third period of walking. Curve B in figure 31 shows essentially the same characteristics as those of curve A in the same figure.

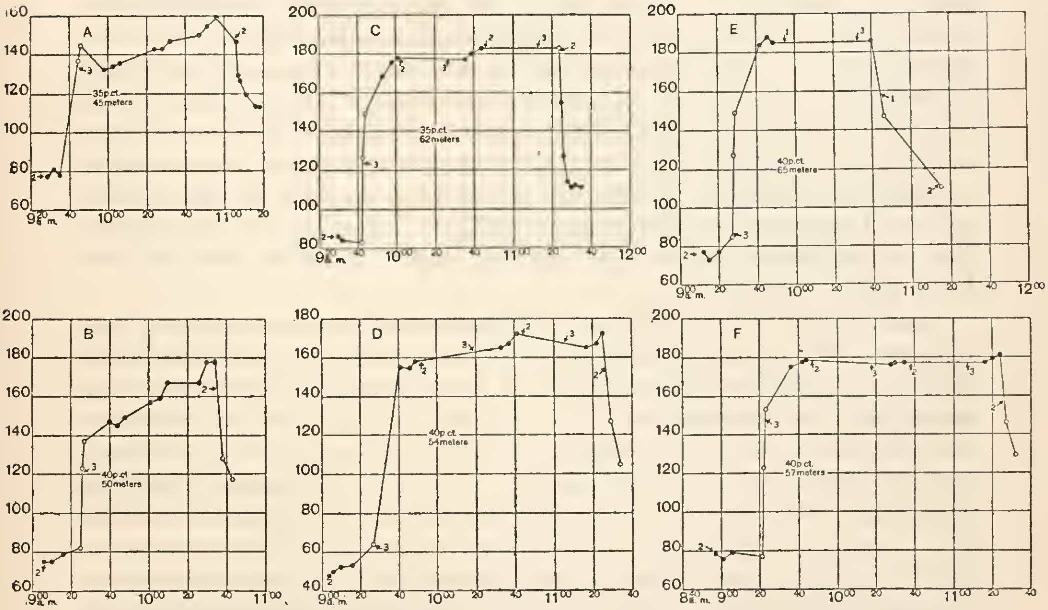

Fig. 32.—Typical pulse curves of E. D. B., with subject standing, and walking on an incline. (Values per minute.)

1, subject sitting; 2, standing; 3, walking on an incline. Black points, records during experimental periods; open circles, records between periods. Curve A, Feb. 15; B, Feb. 18; C, Feb. 17; D, Feb. 19; E, Feb. 22; F, Feb. 21, 1916.

In figure 32 curves A and B represent pulse records obtained when the walking was continuous and illustrate the gradual rise in the pulse-rate due to the cumulative effect of the exercise. As no records of the pulse-rate were made in the intervals between the walking periods in the other experiments in figure 32, there is accordingly no picture of the fall which took place while the subject was standing in these intervals. (See C, D, E, and F.) The curves in other respects are similar to those previously discussed, and show increases in the pulse-rates of 60 to 80 beats or more in the first period of walking. Curve E represents the records for the day on which E. D. B. performed the maximum amount of work (February 22), which was accompanied by the maximum pulse-rate and the maximum oxygen consumption. In this experiment, also, no records were made during the intervals between the periods. As will be seen, the severe exercise in the walking periods increased the pulse-rate per minute over 100 beats.

---

[1] Benedict and Cathcart, Carnegie Inst. Wash. Pub. No. 187, 1913, p. 154.

Body-Temperature During Grade Walking.

The measurements of the body-temperature of E. D. B. during grade walking were begun on January 5, 1916, and are given in table 16*a*, page 88. These temperature records were made with a resistance thermometer placed in the rectum (see p. 36), and represent average values. It must be understood that identical conditions did not prevail for all experiments. These differences in the conditions, such as in the length of preliminary walking, the position of the subject between the periods, i. e., sitting, standing, or walking, and the difficulties which sometimes developed due to the displacement of the thermometer as the subject walked or changed from standing or sitting to walking or the reverse, all tend to make direct comparisons difficult. Each record must therefore be considered for the most part by itself. This can best be done by a series of curves.

In table 16*a* the data indicate a temperature rise between most of the periods. When this did not occur, the cause may generally be found in the fact that the subject rested in these intervals and there was accordingly no cumulative effect of work. This rise in temperature can not be due to the diurnal variation which is known to exist, for the periods are too brief and as a rule the differences between succeeding periods were from 0.1° to 0.3° C. Differences of over 1° C. are occasionally found, which may be due to the cumulative effect of work. On March 4 there was a fall of 1° C. between the second and third periods. The subject was sitting in the interval between these periods and the temperature fell continuously during that time. It continued to fall for several minutes after the walking in the third period began and remained at the lower level during the walking in the fourth period. Evidently the technique was at fault on this date, although no mention is made in the protocols of any difficulty.

Temperature records taken on 14 different days are given in figures 33 to 37. The times of change from sitting to standing or standing to walking or the reverse are indicated by arrows and the usual numeral designations, i. e., 1, sitting; 2, standing; 3, walking on an incline. As in the pulse curves, the black points represent records taken during the experimental periods, and the open circles the records between the periods. Although all of the body-temperature material for these 14 days have been plotted in the curves, it does not seem necessary to reproduce the records for the other days. The data graphically given were selected with a view to showing the body-temperature with a variety of grades and speeds of walking, and the response of the temperature record to the changes from rest to work and the reverse. During the experiments on these days the room temperature was, on the average, about 21° C., varying not more than 2° or 3° C. from this in any experiment.

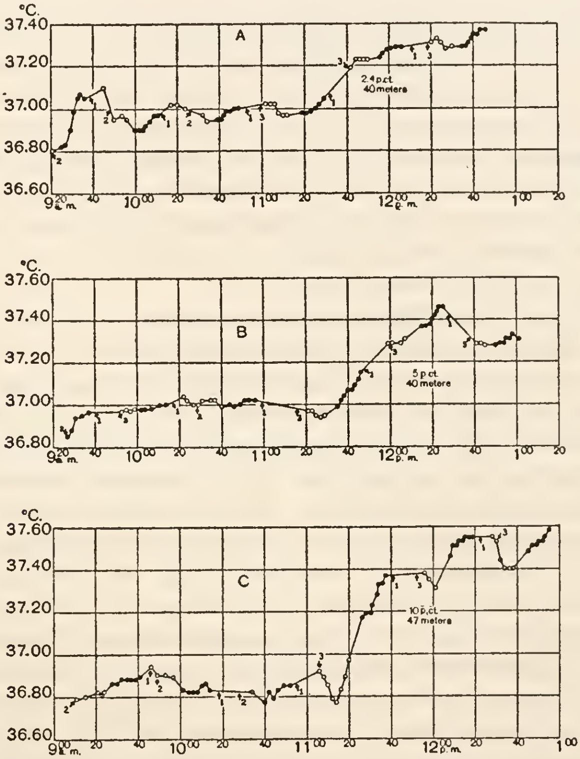

FIG. 33.—Typical body-temperature curves of E. D. B., with subject standing and walking on an incline. (Values per minute.)

1, subject sitting; 2, standing; 3, walking on an incline. Black points, records during experimental periods; open circles, records between periods. Curve A, Apr. 15; B, Apr. 14; C, Apr. 6, 1916.

In figure 33 are three curves (April 15, 14, and 6) for periods with the subject in the standing position, also walking with grades of 2.4, 5, and 10 per cent. The temperatures for the standing position were fairly constant until the point when walking began, which is indicated by the arrow and the numeral 3.[1] The rise in the temperature curve with the change to walking on these three days is not large in comparison with that shown in subsequent figures, the records in figure 33 being chosen for low grades and speeds. This increase does not become apparent for approximately 10 to 15 minutes after the walking began, and the rate of increase is relatively gradual. In the first two curves, A and B, there is usually no noticeable fall in temperature when, as in both experiments, the subject sat down at the close of the walking periods. In the curve for the 10 per cent grade (curve C), a more rapid rise in temperature is evident, with a tendency to a decrease between the periods. This is apparent, also, after the second walking period with the 5 per cent grade in curve B, when the temperature during walking had reached 37.46° C. The curve for the 10 per cent grade (curve C) shows a sudden fall in temperature following the change to walking before the heat due to the exercise becomes noticeable. This was possibly owing to change in resistance of the leads when the subject removed the blanket (see p. 37), or possibly to some change in the position of the thermometer itself.

---

[1] The curves are drawn by connecting the points for the consecutive readings. The locations of the numbers and arrows for change in position refer to the approximate time and not to the temperature.

In figure 34 are three different types of curves (February 2 and 25 and March 8). Here the grades were 25 and 30 per cent, with speeds from 46 to 60 meters per minute. The curves all show an immediate rise in temperature as soon as walking began, the response being within 2 or 3 minutes. This is in contrast to the curves in figure 33. The rise in temperature in curve B was 1.23° C. during 28 minutes of walking, with a maximum of 38.30° C. With the same grade, but a speed of 51 meters, the increase in three periods of walking was 1.45°, 1.49°, and 1.52° C., respectively. (See curve C.) As soon as the walking stopped and the subject sat down, the temperature fell as rapidly as it rose and in approximately 40 minutes had reached the original level. The effect of difference in position may be seen by the fact that the fall at the end of the periods was greater and more rapid in curve C, when the subject sat down with the cessation of walking, than in curve B, when the subject stood in the intervals between the walking periods. In the last period in curve B the walking was stopped, although the measurement of the metabolism was continued somewhat longer. While the rise in temperature ceased and the records almost immediately showed a level when the walking stopped, the fall in temperature in this case did not occur until the close of the period. Curve A in this figure shows a record for an experiment in which but three observations were taken during each period. In this experiment the subject sat down after each period and the temperature did not rise so high nor fall so abruptly as in curve C, in which the grade and speed were greater and the walking was continued through two periods and the corresponding interval before the subject sat down.

In figure 35 are four curves (February 29, 22, 17, and 18) of the temperature changes when E. D. B. was walking with a speed of 68 to 50 meters per minute (2.5 to 2 miles an hour) on a 30 to 40 per cent grade, and performing approximately 1,200 to 1,600 kg. m. of work. With a grade of 30 per cent and a speed of 68 meters per minute, the body-temperature increased regularly during the 32 minutes of continuous walking, reaching a maximum of 38.23° C., with a total rise of 1.63° C. (See curve A.) The fall in temperature when the subject stopped walking and stood, at $10^h\ 55^m$ a. m., was not so rapid as that shown by the curve D when a higher body-temperature was reached, or when the subject sat after walking, as shown by curve C in figure 34. A more rapid fall began at $11^h\ 40^m$ a. m., when the subject sat down, which again was retarded during the standing period of 20 minutes about 12 o'clock. At 1 p. m., after 2 hours and 5 minutes of intermittent standing and sitting, the temperature had not reached the initial level.

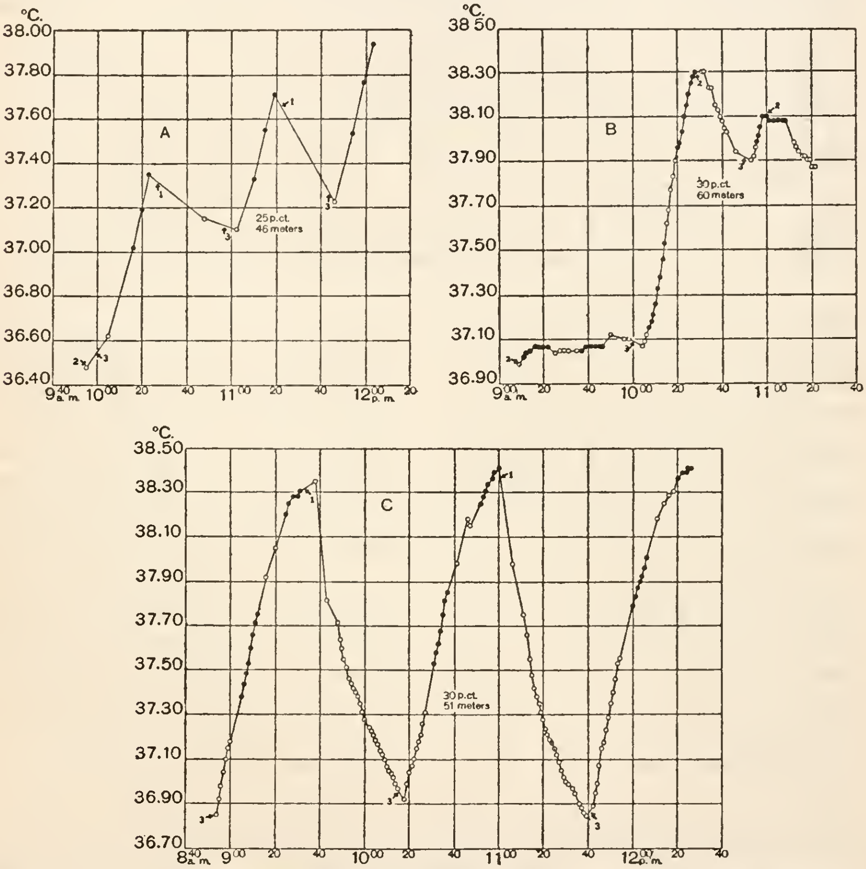

FIG. 34.—Typical body-temperature curves of E. D. B., with subject standing, and walking on an incline. (Values per minute.)

1, subject sitting; 2, standing; 3, walking on an incline. Black points, records during experimental periods; open circles, records between periods. Curve A, Feb. 2; B, Feb. 25; C, Mar. 8, 1916.

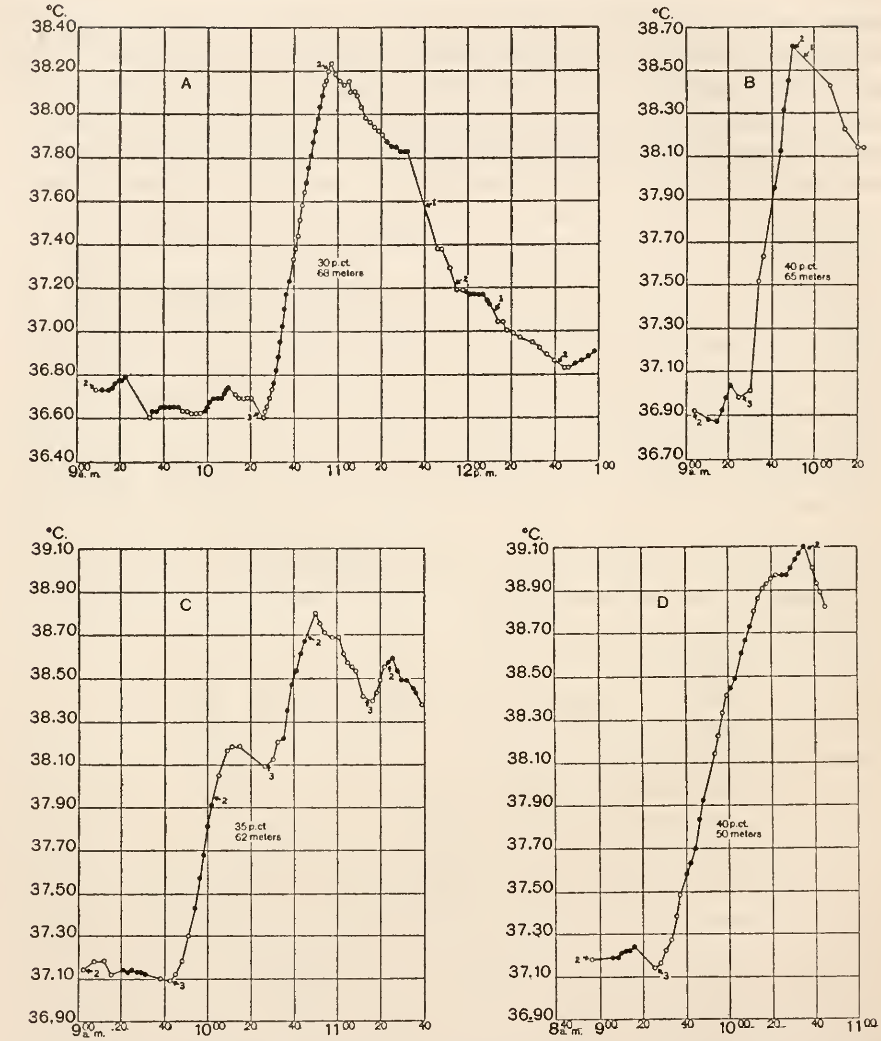

Fig. 35.—Typical body-temperature curves of E. D. B., with subject standing, and walking on an incline. (Values per minute.)

1, subject sitting; 2, standing; 3, walking on an incline. Black points, records during experimental periods; open circles, records between periods. Curve A, Feb. 29; B, Feb. 22; C, Feb. 17; D, Feb. 18, 1916.

Curve C gives the body-temperature for the experiment of February 17, when there was an initial period of standing followed by several periods when the subject walked on a 35 per cent grade at a speed of 62 meters per minute. The subject stood after each walking period. In the first 19 minutes of walking the temperature rose 0.82° C., i. e., at the rate of 0.04° C. per minute. The total effect of the exercise was an increase in the body-temperature of approximately 1.7° C., with a maximum body-temperature of 38.80° C.

In curve D a graphic record is given of the body-temperature found in the experiment of February 18, with E. D. B. walking at an average rate of 50 meters per minute on a 40 per cent grade. Here, also, the walking was preceded by a period of standing, with practically the same body-temperature at the beginning as in curve C. In contrast to February 17, the rise in the first 19 minutes of walking was but 0.66° C., or 0.03° C. per minute. The slope of the curve for the grade walking is practically constant up to 38.50° C., and thereafter the rate of increase diminishes. Although the grade was 5 per cent greater on February 18 than it was on February 17, a decrease in speed of 12 meters per minute resulted in a smaller amount of work on this day (1,188 kg. m. as compared with 1,306 kg. m. on February 17), which was sufficient to retard the rise in the body-temperature. In this experiment there was continuous walking from 9^h 25^m to 10^h 35^m a. m. (1 hour and 10 minutes), with a total increase in temperature of 1.96° C. and a maximum temperature of 39.10° C. The subject was much out of breath when he stopped walking and was sweating freely. As stated earlier, the electric fan was not used for cooling during the experiments with E. D. B. (See p. 37.)

Curve B in figure 35, which gives records for the experiment on February 22, when the grade was 40 per cent and the speed 65 meters per minute, represents the temperature on the day when E. D. B. did his maximum amount of work of 1,569 kg. m. per minute with an oxygen consumption of 3,132 c. c. per minute, and a total heat-output per minute of 15.65 calories. Although the maximum body-temperature was not so great as that shown in curve D, when the walking was continuous for 1 hour and 10 minutes, yet the increment during walking is shown by curve B to have been 1.62° C. in 23 minutes. This was an increase at the rate of 0.07° C. per minute. The rate of increase is thus larger than that shown in curves C and D when the temperature rose 0.04° and 0.03° C. per minute, respectively, and the work performed was less. It may reasonably be said, therefore, that for amounts of work over 1,000 kg. m. per minute, the body-temperature may increase from 0.03° to 0.07° C. per minute for the first 10 to 20 minutes, with a maximum total increase of 1.5° to 2.0° C.

The curves in figure 36 (February 26 and 15) are included to show more especially the fall in the body-temperature after the walking stopped. In the experiment of February 26 (curve A) the grade was 30 per cent and the speed 70 meters per minute. The walking ceased at 10^h 32^m a. m., and in the subsequent period of 2 hours and 3 minutes, during which the man alternately stood and sat, the body-temperature fell 1.58° C. This fall brought the body-temperature below the level in the first standing period of the forenoon.

In the experiment on February 15 the grade was 35 per cent and the speed was 45 meters per minute. When the walking ceased at 11^h 7^m

a. m., the body-temperature decreased rapidly, the fall amounting to 1.14° C. in 12 minutes, or 0.09° C. per minute. Unless the technique was at fault, which has not been revealed by a careful inspection of the records, this change in temperature of the body in cooling is by far the greatest and most rapid we have found. A possible explanation, but one for which our records give no data, is that the subject stood without the usual blanket covering. In this case, with the thin, short-sleeved, and short-legged athletic suit worn by the man, the radiation would be greatly increased. The curve would thus indicate that the unrestricted liberation of heat from the body can be as rapid as the sudden production of heat following the beginning of muscular exercise.

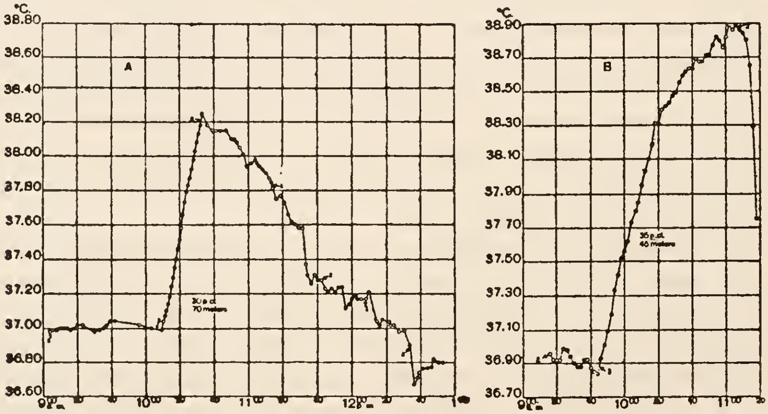

FIG. 36.—Typical body-temperature curves of E. D. B., with subject standing, and walking on an incline. (Values per minute.)
1, subject sitting; 2, standing; 3, walking on an incline. Black points, records during experimental periods; open circles, records between periods.

Figure 37 (a grouping of curves for February 18 and 22, March 23, and April 8) gives four contrasting curves showing typical changes in body-temperature. The curves for the experiments with a 40 per cent grade (February 18 and 22) have already been shown in curves D and B in figure 35. These are in strong contrast to the curves for the experiments of April 8 and March 23, in which the grades were 10 per cent and the speed of walking 36 and 62 meters per minute, respectively. The lowest curve of the four (that for April 8, when the smallest amount of work was done) shows that the rise in temperature was not large and that the fall between the periods was slight. Apparently, at the close of the last period, the rise in temperature was approaching a limit. The curve for the other experiment with a 10 per cent grade (March 23) indicates a more rapid increase in temperature, with a more decided fall between the periods. There is no evidence that the rise had reached its limit when the experiment ceased. The two curves with steeper grade (40 per cent) show similar characteristics, but in greater degree.

The average body-temperature is of special interest in experiments in which the energy changes are determined by direct calorimetry and in which an accumulation of heat in the body escapes direct measurement. The temperatures as here reported may not be considered as representing the average values for the whole body, for, as has been stated in earlier publications,[1] the temperature of the body as a whole has a wide range. The data given here represent the temperature of the rectum only. If, however, we accept these values as representing the body average, we see that the temperature may be increased from 1 to 2 degrees, which, with a body-weight of 60 kg. and an assumed specific heat of 0.83° C., results in a storage of 100 calories of heat in the body, for which allowance must be made in all studies by direct calorimetry. Since, however, the amount of heat stored in the body is dependent on so many conditions, such as clothing, air-currents, and intensity of work, only direct measurements of the body-temperature in each instance can be relied upon to give this value. It should be noted that we used no electric fan or other artificial means (see p. 37) for keeping the subject cool during the experiments, and the changes

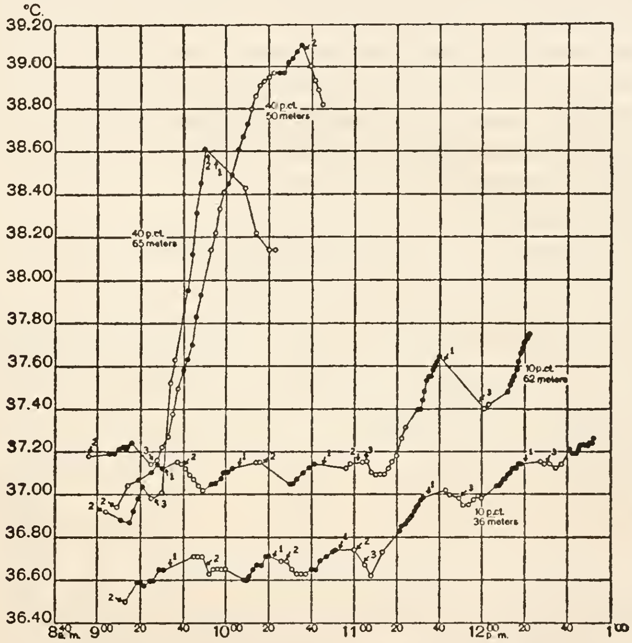

FIG. 37.—Contrasting curves of body-temperature of E. D. B., with subject standing and walking on an incline. (Values per minute.)
1, subject sitting; 2, standing; 3, walking on an incline. Black points, records during experimental periods; open circles, records between periods.

---

[1] Benedict and Snell, Arch. f. d. ges. Physiol., 1901, 88, p. 492; also, Benedict and Slack, Carnegie Inst. Wash. Pub. No. 155, 1911.

are those due to natural radiation and convection as affected by the very light-weight clothing which the subject wore at the time.

Although the temperatures obtained in this study do not show equal increases for similar amounts of work on different days, yet a higher temperature and a greater increase over the normal temperatures during standing were usually observed when the work and the metabolism were greatest. As was found with the pulse-rate, there is evidently a general relation between the amount of work and body-temperature.

BLOOD-PRESSURE DURING GRADE WALKING.

The few readings of the blood-pressure of E. D. B. were made when but small amounts of work were done. Consequently the effect of work on the blood-pressure was not large. As previously stated, these readings were of the systolic pressure only, and were made with the subject standing after a preliminary walking period and again just after the experimental period closed. The results of these measurements, which comprise those for 7 days with grade walking, are given in table 16*a*, page 88.

TABLE 80.—*Blood-pressure of E. D. B. during grade walking in experiments without food. (Values per minute.)*

Date.	Blood-pressure during—		Increase in blood-pressure due to walking.	Amount of work done in walking.
	Standing.	Walking.		
1916.	*mm.*	*mm.*	*mm.*	*kg. m.*
Mar. 23.....	114	118	4	380
24.....	120	127	7	310
Apr. 6.....	116	126	10	284
7.....	119	130	11	281
8.....	125	139	14	223
14.....	116	128	12	126
15.....	118	128	10	59

Excepting for the first period of April 6, the records show close agreement for the periods of the same day, with a slight tendency to increase during the forenoon. The blood-pressure increased over the standing values in all instances, as may be seen from table 80, in which both these values and the kilogrammeters of work done are given. The range of increase was from 4 to 14 mm., with an average value of 10 mm. The blood-pressure for the walking period of March 23 is probably too low, as there was a lapse of 2 minutes after the walking ceased before the pressure was read.

There appears to be no indication in these figures of direct connection between the amount of work performed and the blood-pressure, but up to a certain point it appears that the increase in the blood-pressure found during grade walking over the values obtained with the subject standing is inversely proportional to the amount of work done. This can hardly be regarded as significant, and the probable explanation lies in the technique, for, though the procedure was uniform, there was probably a variation of 10 to 15 seconds between the cessation of work and the time of reading the pressure. Cotton, Rapport, and Lewis[1] have shown that the blood-pressure changes rapidly on cessation of exercise, rising abruptly for the first 20 to 60 seconds and then falling to normal in from 1 to 4 minutes. With such small differences in the blood-pressure as here reported, any error in the time of reading would account for this lack of uniformity between the work and the increase in the blood-pressure.

The values found are similar in degree to those obtained for the same subject when he was walking on a level (see table 11*a*, p. 67), though the increases over the standing values are here a trifle higher on the whole. It is evident that these measurements do not cover a sufficiently wide range of work to warrant an estimate of the effects of grade walking upon the blood-pressure, other than to note an approximate increase of 10 mm. in blood-pressure when the work was 300 kg. m. or less. This increase corresponds roughly to an average increase in the oxygen consumption of 500 c. c. per minute,[2] or 9 c. c. per kilogram of body-weight, which is of the same range as that found in the experiments with level walking. Liljestrand and Stenström[3] with the subject N. S. during level walking found an oxygen increase of 850 c. c. for a rise of 10 mm. in blood-pressure, while for the much lighter subject G. L. the increase in the oxygen consumption was 650 c. c. for an increase of 8 mm. in blood-pressure. These increases would correspond to an increase in the oxygen consumption of 8 and 10 c. c. per kilogram of body-weight.

Physiological Changes in Transition from Standing to Grade Walking and the Reverse.

It is of importance to find out, if possible, how quickly the body responds to the demands made upon it when varying amounts of muscular work are done and how soon it may be said that the body has adapted itself to the new conditions, for the comparison of the results obtained in this research presupposes that the metabolism has not suffered any change in degree within the daily experimental period and that a sufficient period of exercise has been allowed before the beginning of each day's observations for the bodily functions to become settled. It is, furthermore, important to determine how long the effects of muscular work are present after the subject is again at rest. Observations were accordingly made in the grade-walking experiments of the changes in the rates of respiration, pulmonary ventilation, oxygen consumption, and pulse during the transition from standing to walking and from walking to standing.

---

[1] Cotton, Rapport, and Lewis, Heart, 1917, **6**, p. 269.

[2] See table 59, p. 229.

[3] Liljestrand and Stenström, Skand. Arch. f. Physiol., 1920, **39**, p. 211.

The data for the transitional changes in the respiration, pulmonary ventilation, and oxygen consumption were secured by employing the records of the kymograph according to the methods already described in giving the results of the study on the effect of the mouthpiece upon the same factors. (See p. 182.) A reproduction of two typical kymograph records obtained in these transition periods is given in figure 38. The lower record (*A*) represents the change from standing to grade walking, and the upper record (*B*) the change from grade walking to standing. The exact point when the change occurred is indicated in both cases by an arrow. The hill-and-valley effect due to the refilling of the spirometer with oxygen, and referred to on page 182, may be noted in these records.

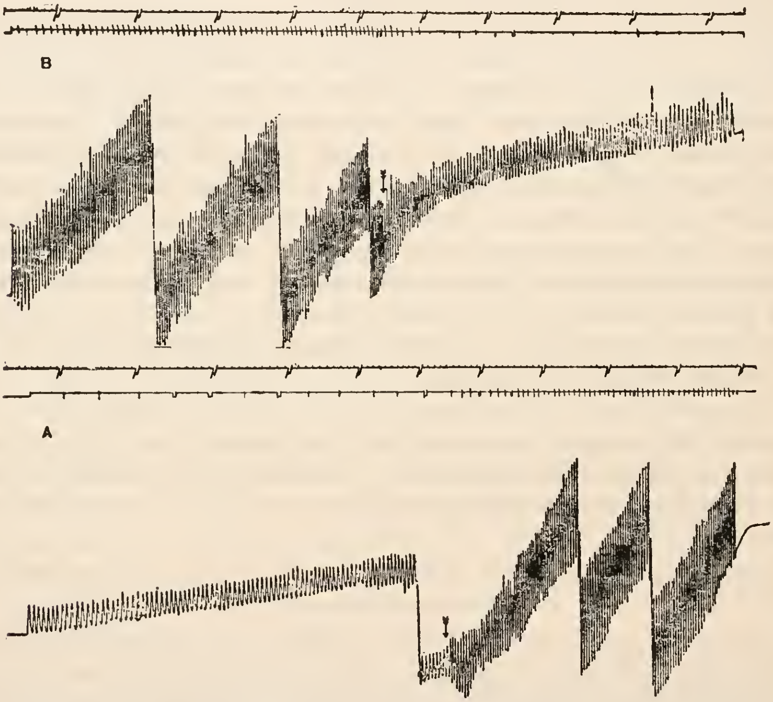

Fig. 38.—Typical kymograph records of respiration, pulmonary ventilation, and rate of oxygen consumption in periods of transition from standing to walking and the reverse.

A, standing to walking. *B*, walking to standing. The arrows indicate the exact point when change occurred. Records of time and pulmonary ventilation adder above each kymograph tracing.

Respiratory Changes in Transition from Standing to Grade Walking.

The observations of the changes due to transition from standing to grade walking were made with the subject standing for 3 or more minutes; the treadmill was then started, and the tracings on the kymograph were noted as the subject walked. The data recorded in tables

81 and 82 were obtained by measuring these kymograph records. The length of time the subject had been standing previous to these transition observations varied considerably, the range being 10 to 50 minutes.

As the condition in the transitional periods varied widely, averaging the values, as was done in the regular series of experiments, would give results without significance. The results of each period have therefore been grouped separately and the measurements of the respiration, ventilation, and oxygen consumption for fractions of a minute have been tabulated on the per minute basis. The data for pulmonary ventilation and oxygen consumption, as given in tables 81 and 82, have not been corrected for the temperature changes, as they are intended for approximate comparison only.

CHANGES IN RESPIRATION-RATE.

The data for the respiration-rate are given in table 81. The respirations during the standing before walking were measured from the kymograph curve for full minutes, no measurements being made of the respiration during the last minute of standing, when the blanket was removed from the subject before he began walking. During the first minute of walking each measurement covered approximately 12 seconds and in the succeeding minutes 15 seconds. As given in the table, however, the respirations for these fractions of a minute have been computed to a per minute rate.

By inspecting the figures in table 81, it will be seen that the respiration-rate for standing was fairly uniform during the time of measurement, the changes from period to period being slight and thus in keeping with the measurements in the standing experiments previously discussed. (See p. 101.) This gives evidence that the respiration-rate had returned to its normal standing value following the walking of the preceding period. In the majority of the periods the increase in the respiration-rate for the first one-fifth minute of walking was at the rate of from 8 to 10 respirations per minute, or, in round numbers, an increase of 50 per cent over the standing rate. During the following fraction of the first minute there was, on the whole, a tendency to a further increase at the rate of 1 to 3 respirations per minute, though in a few instances there was a fall. The major portion of the increase occurred within the first 12 seconds. In the following minutes, measured in 15-second intervals, the rates were, as a rule, higher as the time advanced, and though there are periods when constancy was apparently reached by the second minute (see second period of March 9, fourth period of March 15, and second, third, and fourth periods of March 17), there are others (March 16 and February 24) which show gains throughout the record. The change in the rate due to transition from standing to walking, except with severe grades (see March 16 and February 24), may be said to occur, however, in the first minute, and the most of the change is in the first 12 seconds.

TABLE 81.—*Respiration-rate and pulmonary ventilation of E. D. B. in periods of transition from standing to grade walking. (Values per minute.)*

Date, condition, and period of measurement.	Period I.		Period II.		Period III.		Period IV.	
	Respiration-rate.	Pulmonary ventilation (unreduced).	Respiration-rate.	Pulmonary ventilation (unreduced).	Respiration-rate.	Pulmonary ventilation (unreduced).	Respiration-rate.	Pulmonary ventilation (unreduced).
March 9, 1916.		*liters.*		*liters.*		*liters.*		*liters.*
Standing, measured in minutes......	16.3	10.6	16.5	11.3	17.0	11.5	15.5	10.7
	16.3	10.9	16.8	11.3	16.2	10.6	15.4	10.8
	16.6	11.5	16.2	11.6	17.3	11.6	17.3	11.6
Walking, 30 p. ct.; av., 49.6 meters:								
Measured in 1/5 min.:								
1st......................	20.8	25.2	26.2	24.1	25.8	27.3	25.0	23.6
2d......................	22.5	25.5	23.9	27.8	23.5	29.6	24.0	28.6
3d......................	24.3	31.6	25.0	36.0	23.5	32.6	21.8	33.4
4th......................	25.7	42.6	25.0	42.5	24.8	44.1	24.0	42.1
5th......................	27.9	47.6	24.1	44.4	29.1	51.0	25.7	46.2
Following 1/4 min.:								
1st......................	25.4	44.0	29.9	57.0	27.4	52.5	29.0	57.9
2d......................	25.0	46.0	28.0	55.5	27.4	61.6	30.0	64.5
3d......................	23.9	49.5	24.0	51.9	29.1	58.4	28.0	63.7
4th......................	22.7	49.8	22.5	40.7	25.8	44.8	27.8	54.3
5th......................	24.8	43.1	25.9	41.9	28.7	47.0	28.6	51.2
6th......................	27.1	44.1	24.4	43.1	30.1	51.2	29.8	57.3
7th......................	26.0	45.1	25.1	48.0	31.3	56.2	32.3	62.9
8th......................	27.0	47.2	25.9	52.9	30.1	59.6	33.4	69.5
9th......................	29.1	53.3	23.4	53.7	31.0	69.1	28.2	67.2
10th......................	27.0	55.3	23.4	55.7	28.4	59.6	28.5	59.3
11th......................	27.7	61.9	26.0	63.4	27.4	51.1	24.8	52.6
12th......................	28.4	48.3	28.8	55.6	26.4	47.5	29.1	50.4
13th......................	27.7	44.2	26.5	49.6	28.9	52.2	32.3	60.2.
14th......................	24.9	47.8	24.3	47.8	32.0	62.1	30.0	64.9
15th......................	28.0	52.6	25.3	54.1	32.0	64.0	30.0	68.8
16th......................	29.8	58.3	26.1	60.2	29.3	68.1	30.0	61.8
17th......................	28.3	59.0	28.0	67.0	26.6	51.2	24.8	51.5
18th......................	23.7	55.4	26.9	59.5	28.3	47.4	30.0	55.2
19th......................	23.9	46.4	26.9	48.3	31.0	52.9	28.8	57.1
20th......................	26.8	46.5	26.2	50.6	31.0	56.1	29.8	62.6
21st......................	29.3	51.3	26.2	50.4	....	....	28.7	65.9
22d......................	27.4	52.4	25.8	55.7	....	....	29.8	59.5
23d......................	....	....	....	....	....	....	31.7	59.6
24th......................	....	....	....	....	....	....	32.8	67.9
March 14, 1916.								
Standing, measured in minutes......	16.2	10.7	16.5	10.9	17.5	10.3	17.2	11.2
	15.7	11.2	16.8	11.3	16.4	10.5	17.3	11.6
	16.5	11.7	17.5	12.5	16.5	10.5	17.1	11.1
	17.2	11.5	17.8	13.7	17.4	11.3	17.6	11.8
	16.6	11.9	....	....	....	....	....	....
Walking, 30 p. ct.; av. 59.9 meters:								
Measured in 1/5 min.								
1st......................	26.5	25.2	26.0	24.5	26.6	26.7	26.0	28.7
2d......................	30.2	32.0	28.3	22.2	26.6	26.3	25.0	32.6
3d......................	24.4	36.7	27.9	28.0	25.6	33.8	27.9	35.8
4th......................	23.7	38.7	26.7	35.1	27.3	34.5	27.1	40.5
5th......................	29.3	45.3	28.0	42.1	25.8	42.2	27.9	43.7

TABLE 81.—*Respiration-rate and pulmonary ventilation of E. D. B. in periods of transition from standing to grade walking.* (*Values per minute.*)—Continued.

Date, condition, and period of measurement.	Period I.		Period II.		Period III.		Period IV.	
	Respiration-rate.	Pulmonary ventilation (unreduced).	Respiration-rate.	Pulmonary ventilation (unreduced.)	Respiration-rate.	Pulmonary ventilation (unreduced).	Respiration-rate.	Pulmonary ventilation (unreduced).
March 14, 1916—cont'd.								
Walking, 30 p. ct.; av. 59.9 meters—con.								
Following 1/4 min.:		*liters.*		*liters.*		*liters.*		*liters.*
1st	29.4	49.9	27.6	45.9	25.8	51.2	30.2	49.4
2d	25.4	53.3	28.5	48.9	26.7	52.7	27.3	53.1
3d	26.4	55.4	26.1	51.9	27.2	57.0	29.2	61.2
4th	22.6	51.2	28.6	57.2	27.6	60.3	29.2	64.0
5th	28.7	58.7	30.2	57.6	27.0	64.1	27.1	63.3
6th	27.5	56.2	32.3	59.0	27.6	64.3	25.7	59.2
7th	31.4	64.6	24.8	53.3	24.4	60.4	28.0	61.5
8th	27.1	58.2	26.4	57.5	27.6	64.7	27.1	63.2
9th	29.0	59.7	26.9	56.0	31.0	67.9	28.9	64.4
10th	25.4	53.3	29.7	61.0	33.8	67.0	29.2	66.5
11th	26.3	60.3	29.7	63.2	29.7	64.6	26.6	64.4
12th	29.4	60.6	26.7	53.8	29.2	68.3	25.5	64.6
13th	29.4	59.2	30.5	60.0	26.5	61.1	29.3	69.1
14th	28.1	58.5	29.6	62.2	29.2	68.8	28.7	66.8
15th	......	......	27.5	62.4	28.2	64.9	29.4	65.6
16th	......	......	......	......	26.5	66.1	29.3	68.5
March 15, 1916.								
Standing, measured in minutes	16.3	11.0	15.0	10.2	16.3	11.7	16.5	10.7
	16.8	11.2	16.7	11.0	16.9	11.9	17.6	12.8
	15.5	10.1	16.7	11.3	16.4	9.9	17.4	11.8
	15.3	9.7	16.7	11.3	16.4	11.5	16.5	10.5
	......	......	......	......	......	......	17.1	13.0
Walking, 30 p. ct.; av., 69.6 meters:								
Measured in 1/5 min.:								
1st	34.0	32.9	22.3	24.4	24.1	20.9	20.9	......
2d	26.3	33.5	21.8	35.2	31.9	29.5	19.6	30.6
3d	28.4	31.4	24.5	31.0	24.1	39.5	22.8	40.1
4th	24.5	41.9	24.7	33.7	26.4	37.4	23.5	37.1
5th	26.6	46.8	25.5	44.9	27.5	48.3	29.0	50.0
Following 1/4 min.:								
1st	28.6	53.1	28.8	52.6	25.8	51.3	28.7	53.9
2d	26.0	57.8	29.6	59.0	28.6	60.1	25.3	59.7
3d	29.9	64.4	30.4	61.9	30.2	66.7	26.7	66.7
4th	27.4	61.7	26.2	61.8	27.5	65.9	28.9	72.7
5th	29.6	70.0	25.5	67.1	28.4	71.3	28.3	75.9
6th	30.1	75.3	24.8	67.4	28.4	72.2	28.7	74.6
7th	31.0	76.2	26.5	66.1	28.4	70.1	28.3	72.0
8th	29.3	71.9	29.6	75.1	29.1	76.9	30.4	77.3
9th	28.3	69.4	28.2	76.7	31.2	80.4	25.3	75.9
10th	26.0	72.2	26.3	68.1	30.5	80.2	28.0	78.7
11th	29.0	75.9	26.2	66.9	29.4	72.9	28.6	73.9
12th	29.0	70.3	23.5	64.4	26.7	66.6	28.3	75.8
13th	31.0	73.3	28.9	75.3	24.0	62.9	26.6	74.8
14th	......	......	30.6	75.0	24.0	67.7	30.3	79.4

Table 81.—*Respiration-rate and pulmonary ventilation of E. D. B. in periods of transition from standing to grade walking. (Values per minute.)*—Continued.

Date, condition, and period of measurement.	Period I.		Period II.		Period III.		Period IV.	
	Respiration-rate.	Pulmonary ventilation (unreduced).	Respiration-rate.	Pulmonary ventilation (unreduced).	Respiration-rate.	Pulmonary ventilation (unreduced).	Respiration-rate.	Pulmonary ventilation (unreduced).
March 17, 1916.		*liters.*		*liters.*		*liters.*		*liters.*
Standing, measured in minutes......	14.9	9.7	16.0	10.3	16.3	11.0	17.7	11.2
	14.7	9.9	16.0	10.6	17.4	11.8	17.7	11.0
	14.1	10.0	15.6	10.5	16.6	11.1	17.7	11.2
	13.6	8.8	16.5	10.5	17.0	10.3	16.4	10.9
	15.3	11.2	16.1	10.6	16.7	13.4	16.9	10.8
Walking, 30 p. ct.; av., 52.9 meters:								
Measured in 1/5 min.:								
1st......................	23.8	....	24.0	20.7	24.0	22.0	21.7	18.9
2d......................	26.5	29.4	24.3	26.9	24.0	29.5	26.6	27.7
3d......................	21.2	24.7	24.3	29.5	24.0	29.5	25.4	26.8
4th......................	20.2	29.7	25.2	31.4	25.4	34.5	26.6	36.8
5th......................	23.0	36.4	25.2	35.2	24.4	34.6	27.0	39.9
Following 1/4 min.:								
1st......................	24.9	43.6	26.8	41.4	25.2	40.2	29.3	44.7
2d......................	26.5	47.0	25.5	40.8	25.2	44.1	27.1	45.0
3d......................	26.5	49.3	25.5	42.2	26.1	44.1	25.5	46.4
4th......................	24.6	48.2	26.4	45.4	24.7	43.0	25.7	47.9
5th......................	25.8	52.6	25.1	46.2	24.0	47.6	26.3	51.5
6th......................	23.2	51.4	26.6	47.6	25.5	55.5	25.4	53.1
7th......................	25.8	50.7	24.9	52.8	27.1	56.4	27.8	55.6
8th......................	27.1	50.8	25.2	49.3	26.7	53.4	27.8	53.0
9th......................	25.9	53.3	25.7	47.2	25.7	52.5	26.5	50.6
10th......................	28.0	53.4	27.2	50.7	24.0	51.5	27.1	55.0
11th......................	28.9	56.6	25.5	48.0	28.7	57.3	29.1	57.8
12th......................	24.9	52.9	27.2	51.0	26.4	55.7	26.3	56.0
13th......................	26.4	53.1	27.6	54.8	26.4	55.9	28.2	65.2
14th......................	28.0	59.0	31.0	60.8	26.0	51.8	28.1	56.0
15th......................	26.4	53.9	24.9	50.6	26.2	53.1	26.2	52.7
16th......................	25.5	54.1	25.6	52.1	28.0	55.6	25.4	53.4
17th......................	24.7	53.1	25.6	51.9	28.0	55.9	27.8	56.3
18th......................	....	....	27.2	54.2	28.0	58.6	24.6	55.9
March 16, 1916.								
Standing, measured in minutes:.....	15.0	10.2	15.3	10.2	17.0	9.3	16.3	7.8
	16.1	8.3	16.7	8.1	16.3	7.9	15.9	8.3
	15.1	7.3	14.0	6.7	13.4	6.3	16.6	7.0
	16.3	7.6	15.4	7.4	17.8	7.6	18.5	7.7
	18.0	12.4	16.3	9.8	18.3	11.2	....	....
Walking, 40 p. ct.; av., 66.1 meters:								
Measured in 1/5 min.:								
1st......................	27.2	26.1	26.7	25.0	21.7	29.1	24.8	32.2
2d......................	24.7	31.7	28.2	27.8	20.9	32.0	24.0	43.3
3d......................	28.7	33.9	20.8	33.9	24.3	30.9	26.7	45.2
4th......................	26.3	43.3	20.0	39.1	24.8	36.8	27.9	43.5
5th......................	26.3	50.3	19.2	40.4	23.4	37.8	23.1	49.2

TABLE 81.—*Respiration-rate and pulmonary ventilation of E. D. B. in periods of transition from standing to grade walking.* (*Values per minute.*)—Continued.

Date, condition, and period of measurement.	Period I.		Period II.		Period III.		Period IV.	
	Respiration-rate.	Pulmonary ventilation (unreduced).	Respiration-rate.	Pulmonary ventilation (unreduced).	Respiration-rate.	Pulmonary ventilation (unreduced).	Respiration-rate.	Pulmonary ventilation (unreduced).
March 16, 1916—cont'd.								
Walking, 40 p. ct.; av. 66.1 meters—con.								
Following 1/4 min.:		*liters.*		*liters.*		*liters.*		*liters.*
1st	26.6	58.3	21.6	51.0	25.3	51.0	23.4	59.8
2d	28.0	67.4	24.4	61.3	29.3	70.8	24.7	69.9
3d	24.6	66.5	29.6	79.1	26.6	71.3	31.4	87.5
4th	27.1	77.5	29.4	78.0	27.3	79.6	29.9	88.6
5th	27.5	76.8	27.5	80.0	31.2	88.0	34.1	99.7
6th	27.5	84.1	31.0	90.1	34.0	98.9	31.4	96.5
7th	28.9	86.3	31.0	93.9	32.9	98.8	34.1	98.4
8th	30.4	88.4	31.0	94.5	36.0	109.9	34.1	98.4
9th	30.0	88.2	29.9	96.3	32.4	97.0	36.0	106.8
10th	31.8	97.1	31.0	97.2	31.5	96.5	37.1	110.0
11th	28.6	91.1	29.9	93.7	34.7	103.4	36.5	108.4
February 24, 1916.								
Standing, av. of 3 minutes	......	......	......	......	16.7	12.2	......	......
Walking, 45 p. ct.; av., 44.8 meters:								
Measured in 1/5 min.:								
1st	......	......	......	......	25.9	24.7	......	......
2d	......	......	......	......	20.8	21.2	......	......
3d	......	......	......	......	25.9	26.1	......	......
4th	......	......	......	......	25.4	29.3	......	......
5th	......	......	......	......	27.7	35.1	......	......
6th	......	......	......	......	29.3	37.0	......	......
7th	......	......	......	......	29.3	44.8	......	......
8th	......	......	......	......	25.4	44.7	......	......
9th	......	......	......	......	28.9	50.1	......	......
10th	......	......	......	......	31.2	56.5	......	......
11th	......	......	......	......	27.9	50.3	......	......
12th	......	......	......	......	24.1	51.4	......	......
13th	......	......	......	......	28.1	51.9	......	......
14th	......	......	......	......	30.0	58.2	......	......
15th	......	......	......	......	29.0	61.5	......	......
16th	......	......	......	......	26.3	49.5	......	......
17th	......	......	......	......	35.0	73.2	......	......
18th	......	......	......	......	39.2	92.6	......	......
19th	......	......	......	......	33.7	89.4	......	......
20th	......	......	......	......	31.3	81.9	......	......
21st	......	......	......	......	31.3	85.8	......	......
22d	......	......	......	......	33.7	92.9	......	......
23d	......	......	......	......	30.0	87.1	......	......
Following minutes:								
1st	......	......	......	......	32.0	90.5	......	......
2d	......	......	......	......	34.0	96.6	......	......
3d	......	......	......	......	34.0	95.1	......	......
4th	......	......	......	......	36.5	101.6	......	......

CHANGES IN PULMONARY VENTILATION.

The data for the pulmonary ventilation (uncorrected for temperature changes) are also included in table 81, and are measured from the kymograph curves in the same time-lengths as the respiration-rate, i. e., full minutes for the standing position and 12 seconds and 15 seconds for the walking. When the subject changed from standing to walking, the measured values indicate that the ventilation doubled within the first 12 seconds and continued to increase throughout the first and into the second minute. By the close of the second minute this increase appeared to diminish in several of the periods, but, as a rule, it continued into the third minute. Beyond the third minute, though increases occasionally appear in the values, they were not persistent, and are without uniformity in direction. The values in the fifth minute are seldom larger or even as large as those found in some of the earlier minutes. While the figures show wide variations, the general picture which they convey is that the immediate effect of the work upon the ventilation was compensated for by the end of the third, or possibly the beginning of the fourth minute, and probably the ventilation reached approximate constancy by the time the subject had maintained a uniform rate of walking for 4 minutes. The ventilation during the periods on March 9 had a decided rhythmic effect which makes it uncertain whether or not on this day the effect of the work on the ventilation was offset by the third minute. This rhythm, however, is not apparent on any of the other days.

CHANGES IN RATE OF OXYGEN CONSUMPTION (UNREDUCED).

The changes in the rate of the oxygen consumption (unreduced) as the subject passed from standing to walking are shown in table 82. These include data for both standing and walking on March 9, 14, 15, 16, and 17, 1916. A few values obtained on February 24 are also given.

Table 82.—*Rate of oxygen consumption of E. D. B. in periods of transition from standing to grade walking.*

Date, condition, and period of measurement.	Oxygen consumption (unreduced) per minute.			
	Period I.	Period II.	Period III.	Period IV.
March 9, 1916.	*c. c.*	*c. c.*	*c. c.*	*c. c.*
Standing, measured in minutes	269	269	290	....
	290	280	301	301
	301	290	301	301
Walking; 30 p. ct.; av., 49 meters:				
Measured in ½ min.:				
2d	1,527	1,484	1,398	1,527
3d	1,570	1,558	1,387	1,527
4th	....	1,667	2,008	1,955

TABLE 82.—*Rate of oxygen consumption of E. D. B. in periods of transition from standing to grade walking.*—Continued.

Date, condition, and period of measurement.	Oxygen consumption (unreduced) per minute.			
	Period I.	Period II.	Period III.	Period IV.
March 9, 1916—cont'd.				
Walking, 30 p. ct.; av. 49 meters—cont'd.				
Measured in ½ min.—cont'd.	*c. c.*	*c. c.*	*c. c.*	*c. c.*
5th	2,000	1,978	2,000	2,021
6th	1,957	1,935	1,978	2,107
7th	1,828	1,729	....	2,247
8th	2,020	2,494	2,107	2,236
9th	2,021	2,193	2,064	2,236
10th	2,043	2,107	2,116	2,261
11th	2,135	....	2,344	2,301
12th	2,215	2,086	2,408	2,279
13th	2,272	2,150	....	2,174
14th	....	....	....	2,129
March 17, 1916.				
Standing, measured in minutes	312 323 269 258	237 280 344 258 312	344 376 312 269	312 290 333 301 247
Walking, 30 p. ct.; av., 53 meters:				
Measured in ½ min.:				
1st	....	....	1,139	....
2d	1,312	1,462	1,613	1,247
3d	2,021	1,699	1,957	1,892
4th	2,172	1,871	1,914	2,215
5th	2,233	1,935	1,978	2,282
6th	2,279	2,287	2,451	2,430
7th	2,344	2,236	2,451	2,473
8th	2,452	2,279	2,483	2,428
9th	2,387	2,334	2,473	2,277
10th	2,344	2,430	2,408	2,322
11th	2,335	2,344	2,408	2,322
March 14, 1916.				
Standing, measured in minutes	269 301 333 237 258	290 269 247 215	258 258 269 258	258 301 323 215 ....
Walking, 30 p. ct.; av., 60 meters:				
Measured in ½ min.:				
1st	....	....	....	1,288
2d	2,129	1,560	1,140	1,441
3d	1,957	1,828	1,914	1,806
4th	2,057	2,322	2,258	2,150
5th	2,561	2,580	2,262	....
6th	2,752	2,462	2,449	2,537

TABLE 82.—*Rate of oxygen consumption of E. D. B. in periods of transition from standing to grade walking*—Continued.

Date, condition, and period of measurement.	Oxygen consumption (unreduced) per minute.			
	Period I.	Period II.	Period III.	Period IV.
March 14, 1916—cont'd.				
Walking, 30 p. ct.; av. 60 meters—cont'd.				
Measured in ½ min.—cont'd.	*c. c.*	*c. c.*	*c. c.*	*c. c.*
7th	2,724	2,473	2,408	2,494
8th	2,694	2,469	2,408	2,551
9th	2,666	2,494	2,484	2,795
10th	....	2,437	2,365	2,693
March 15, 1916.				
Standing, measured in minutes	312	290	312	....
	301	280	280	323
	323	258	258	323
	....	312	258	258
Walking, 30 p. ct.; av., 70 meters:				
Measured in ½ min.:				
2d	1,548	....	1,505	1,871
3d	2,043	2,129	2,064	1,914
4th	2,614	2,150	2,494	2,387
5th	2,688	2,772	2,855	2,749
6th	2,774	2,989	2,881	2,752
7th	....	3,141	2,820	3,023
8th	3,075	2,989	2,817	3,118
9th	3,035	2,838	2,881	3,144
March 16, 1916.				
Standing, measured in minutes	....	333	355	312
	....	....	355	290
	258	280	344	366
	323	321	....	258
Walking, 40 p. ct.; av., 66 meters:				
Measured in ½ min.:				
1st	....	....	1,363	....
2d	1,697	1,957	1,656	1,937
3d	2,150	2,279	2,043	2,559
4th	2,634	3,047	2,094	3,395
5th	3,268	3,161	3,698	3,440
6th	3,326	3,293	3,333	3,505
7th	3,354	3,311	3,419	3,483
8th	....	....	3,611	....
February 24, 1916.				
Standing, av. of 3 minutes	....	....	287	....
Walking, 45 p. ct.; 45 meters:				
Measured in 1/5 min.:				
1st	....	....	556	....
2d	....	....	560	....
3d	....	....	649	....
4th	....	....	874	....
5th	....	....	835	....
6th	....	....	1,207	....
7th	....	....	1,364	....
8th	....	....	1,530	....

The values for the oxygen consumption during standing are measured in minutes from the kymograph record during 3 or more of the 5 or 6 minutes preceding the time of transition to walking. These unreduced values for the oxygen consumption range somewhat about an average of 300 c. c. per minute. On March 16, especially in the first, second, and fourth periods, the respiration was uneven and the measurement of the kymograph curve was difficult.

During the first 30 seconds of walking, the tracings were usually too irregular to determine the rate of oxygen consumption, but in the second half-minute we find the oxygen consumption was in almost every instance over 1,400 c. c., or from four to five times the standing requirement. As a rule, in the third half-minute the oxygen consumption increased an additional 300 to 500 c. c., or a further increase of about one-quarter of that which occurred in the second half-minute. The values for the fourth half-minute are approximately of the same character as those in the third half-minute, but with the increases over the preceding half-minute somewhat diminished. By the fifth half-minute, and certainly by the sixth half-minute (from 2½ to 3 minutes after the walking began), the oxygen consumption apparently reached a point indicating that the rate of consumption was commensurate with the body requirements for the work in hand. Beyond this point the rate of oxygen consumption remained essentially uniform for the remainder of the experimental period, irrespective of the amount of work being performed.

Respiratory Changes in Transition from Grade Walking to Standing.

The respiratory changes during the transition from grade walking to standing were also measured in like manner as those for the transition from standing to grade walking. (See fig. 38, p. 278.) The values for the respiration-rate and pulmonary ventilation are given in tables 83 and 84 and for the rate of oxygen consumption in table 85.

In eight of these experiments the transition was measured during the final standing period after the subject had been walking during the preceding periods of the forenoon. The walking stopped simultaneously with the beginning of the period and the respiration-rate and pulmonary ventilation were measured and compared with the average values for the preceding walking periods. (See table 83.) On only three of these days was an attempt made to estimate the oxygen consumption, and then only with the subject standing.

On March 10 and 11, in addition to the preliminary walking, the subject walked 3 or 4 minutes of the period and then stood. Observations for four periods were obtained on these two days. During these periods, the respiration, ventilation, and oxygen consumption were determined for both the walking and standing portions. (See tables 84 and 85.) The subject rested in the intervals between periods and then had a preliminary walk in order to make the conditions as nearly alike as possible.

CHANGES IN RESPIRATION-RATE.

The respiration-rates during the walking periods show variations in the measurements per minute, but, on the whole, indicate what may be accepted as the average for walking in each period. A comparison of these rates with those obtained immediately after walking ceased shows that the respiration-rate falls during the first 12 seconds of standing in all but three instances, i. e., February 14 and 15, and the second period of March 10. The decline is small in some cases, and none of the decreases exceed the rate of 6.5 respirations per minute, while the rate for the majority is less than 4 respirations per minute. In the succeeding fractions of the first minute the records show increases and decreases without uniformity, although by the end of the minute the rates may possibly be said to be lower on the whole than at the beginning of the standing. The notable fact is that the change in respiration-rate is slight in the transition from walking to standing. Furthermore, if 16 respirations per minute be taken as the normal respiration-rate for E. D. B. in the standing position, we find that in one or two instances this value is approached during the second or third minute after walking ceased, but the rate is not maintained. In nearly every case the rate is above the normal standing value during the fifth minute, while most of those records which extend into the seventh and eighth minutes show that the respiration-rate is still above the normal. This course is in contrast to the behavior of the respiration-rate in the transition from standing to walking, for the response under those conditions was largely within the first 12 seconds and a uniform rate had been attained by the end of the first minute of walking.

TABLE 83.—*Respiration-rate and pulmonary ventilation of E. D. B. in periods of transition from grade walking to standing.* (*Values per minute.*)

Date, condition, and period of measurement.	Respiration-rate.	Pulmonary ventilation (unreduced).
January 1, 1916.		
Walking, 20 p. ct.; 81.6 meters:		*liters.*
Meas. in minutes	31.0	53.0
	30.6	51.7
Last full minute	27.6	54.2
Standing:		
Meas. in 1/5 min.:		
1st	26.5	49.3
2d	21.2	38.0
3d	26.5	35.1
4th	26.5	35.4
5th	21.8	25.6
January 1, 1916—cont'd.		
Standing—cont'd.		
Meas. in 1/5 min.—cont'd		*liters.*
6th	25.0	30.4
7th	24.0	24.1
8th	22.9	22.8
9th	18.5	18.3
10th	22.2	19.0
11th	19.2	22.1
12th	20.0	13.3
13th	21.8	12.8

TABLE 83.—*Respiration-rate and pulmonary ventilation of E. D. B. in periods of transition from grade walking to standing. (Values per minute.)*—Continued.

Date, condition, and period of measurement.	Respiration-rate.	Pulmonary ventilation (unreduced).
January 1, 1916—cont'd.		
Standing—cont'd.		
Meas. in 1/5 min.—cont'd.		*liters.*
14th	22.2	12.2
15th	20.3	11.1
16th	17.0	9.9
17th	14.7	10.4
18th	11.0	5.2
19th	18.2	8.9
Following 1/2 min.:		
1st	19.9	10.1
2d	20.7	10.8
3d	21.7	9.7
4th	19.9	10.9
5th	19.3	10.8
6th	18.9	9.6
January 3, 1916.		
Walking, 25 p. ct.; 42.3 meters:		
Meas. in minutes	24.0	30.1
	24.6	31.2
Last full minute	23.2	32.6
Standing:		
Meas. in 1/5 min.:		
1st	22.5	30.4
2d	20.9	25.1
3d	17.1	20.2
4th	20.0	21.1
5th	25.7	21.0
6th	21.8	21.8
7th	19.2	16.8
8th	21.8	16.2
9th	20.0	14.2
10th	20.9	15.5
11th	20.9	14.5
12th	20.0	15.0
13th	19.2	13.4
14th	15.8	12.5
15th	19.4	14.0
16th	19.4	12.0
17th	21.0	12.8
18th	20.2	14.1
Following 1/2 min:		
1st	21.3	13.5
2d	20.0	12.8
3d	20.4	13.5
4th	18.4	12.3
January 3, 1916—cont'd.		
Standing—cont'd.		
Following ½ min.—cont'd.		*liters.*
5th	20.0	12.9
6th	19.0	12.2
February 12, 1916.		
Walking, 30 p. ct.; 74.6 meters:		
Meas. in min	31.6	71.8
	27.6	67.3
	29.2	70.8
	29.2	70.4
	28.7	71.0
Last full minute	28.8	71.4
Standing:		
Meas. in 1/5 min.:		
1st	26.7	67.9
2d	26.7	65.8
3d	28.1	55.0
4th	31.4	43.6
5th	26.7	37.0
6th	22.3	34.6
7th	26.7	28.5
8th	28.1	29.9
9th	26.2	30.6
10th	23.4	27.2
11th	22.3	23.7
12th	19.3	19.2
13th	20.5	17.3
14th	16.6	11.7
15th	18.6	10.9
16th	19.3	12.7
17th	21.9	15.4
18th	22.1	15.4
19th	21.9	16.3
20th	21.9	15.8
21st	21.1	18.3
Following 1/2 min.:		
1st	24.2	17.5
2d	19.8	17.4
3d	24.4	15.8
4th	21.0	14.2
5th	22.4	16.4
6th	20.7	15.2
7th	20.0	14.1
8th	19.7	15.3

Table 83.—*Respiration-rate and pulmonary ventilation of E. D. B. in periods of transition from grade walking to standing. (Values per minute.)*—Continued.

Date, condition, and period of measurement.	Respiration-rate.	Pulmonary ventilation (unreduced).
February 14, 1916.		
Walking, 30 p. ct.; 68.8 meters;		*liters.*
Meas. in minutes	29.7	61.8
	27.5	63.4
	32.2	68.3
	25.9	61.3
	24.1	62.6
Standing:		
Meas. in 1/5 min.:		
1st	30.7	75.2
2d	29.6	63.7
3d	29.6	56.2
4th	30.7	43.7
5th	31.8	35.1
6th	29.6	37.6
7th	26.5	35.0
8th	26.7	32.8
9th	26.5	26.5
10th	27.6	21.5
11th	21.6	12.6
12th	19.7	12.8
13th	21.2	18.9
14th	23.8	17.3
15th	25.6	12.6
16th	25.9	14.1
17th	24.6	17.2
18th	24.0	15.8
19th	24.6	19.3
20th	22.2	17.2
21st	22.3	16.2
22d	18.4	12.7
23d	21.0	13.7
24th	20.3	11.6
Following 1/2 min.:		
1st	19.3	15.3
2d	19.5	13.2
3d	20.7	13.8
4th	20.5	14.1
5th	20.8	14.7
6th	19.6	13.9
February 15, 1916.		
Walking, 35 p. ct.; 46.2 meters:		
Meas. in minutes	31.3	46.9
	29.8	46.9
Last full minute	29.2	47.0
Standing:		
Meas. in 1/5 min.:		
1st	34.1	54.2
February 15, 1916—cont'd.		
Standing—cont'd.		
Meas. in 1/5 min.—cont'd.		*liters.*
2d	34.1	45.5
3d	29.2	41.8
4th	29.2	28.7
5th	22.0	37.1
6th	26.4	31.2
7th	30.0	23.2
8th	22.9	24.8
9th	22.0	22.2
10th	22.5	21.6
11th	21.9	16.1
12th	17.7	11.5
13th	16.9	10.5
14th	18.9	12.3
15th	15.4	8.4
16th	21.2	15.8
17th	20.5	19.0
18th	23.4	14.8
19th	18.9	12.8
20th	20.7	14.1
21st	20.7	12.8
22d	20.0	15.5
23d	16.0	15.4
24th	19.1	16.2
25th	20.7	10.8
26th	24.0	15.3
27th	22.9	13.8
28th	24.0	14.5
29th	24.0	21.2
Following 1/2 min.:		
1st	20.6	15.3
2d	19.1	12.5
3d	21.6	14.6
4th	20.8	14.4
February 16, 1916.		
Walking, 35 p. ct.; 56.6 meters;		
Meas. in minutes	30.4	59.9
	28.2	58.4
Last full minute	28.8	59.2
Standing:		
Meas. in 1/5 min.:		
1st	28.4	51.4
2d	30.7	48.9
3d	27.1	43.5
4th	26.4	35.4
5th	25.4	34.6

Table 83.—*Respiration-rate and pulmonary ventilation of E. D. B. in periods of transition from grade walking to standing.* (*Values per minute.*)—Continued.

Date, condition, and period of measurement.	Respiration-rate.	Pulmonary ventilation (unreduced).
February 16, 1916—cont'd.		
Standing—cont'd.		
Meas. in 1/5 min.—cont'd.		*liters.*
6th	25.4	30.6
7th	25.4	19.5
8th	27.6	21.3
9th	24.0	24.1
10th	24.0	22.0
11th	20.8	21.4
12th	19.2	15.9
13th	18.4	18.9
14th	18.4	17.9
15th	17.7	13.9
16th	13.3	9.4
17th	16.9	13.4
18th	20.8	14.8
19th	22.7	14.5
20th	20.0	14.0
Following 1/2 min.:		
1st	21.5	16.3
2d	21.3	14.2
3d	19.4	14.6
4th	19.5	13.5
5th	20.5	13.2
6th	22.7	15.7
February 17, 1916.		
Walking, 35 p. ct.; 62.5 meters:		
Meas. in minutes	30.0	69.5
	27.2	67.1
	28.5	69.8
	29.3	71.8
Last full minute	29.0	71.2
Standing:		
Meas. in 1/5 min.:		
1st	24.8	57.0
2d	29.7	52.1
3d	30.3	44.1
4th	29.7	46.4
5th	23.6	42.7
6th	28.4	25.3
7th	22.6	27.6
8th	21.7	20.8
9th	19.8	18.4
10th	21.7	19.9
11th	23.2	19.0
12th	21.1	18.5
February 17, 1916—cont'd.		
Standing—cont'd.		
Meas. in 1/5 min.—cont'd.		*liters.*
13th	23.2	17.8
14th	23.2	17.3
15th	23.2	16.0
16th	23.3	18.1
17th	21.6	15.9
18th	22.0	16.1
19th	22.0	19.3
20th	19.4	15.7
Following 1/2 min.:		
1st	22.1	16.6
2d	21.8	16.5
3d	19.9	16.0
4th	20.4	13.5
Following minutes:		
1st	20.0	14.8
2d	20.4	15.1
February 25, 1916.		
Walking, 30 p. ct.; 59.6 meters:		
Last full minute	32.0	50.3
Standing:		
Meas. in 1/5 min.:		
1st	25.5	44.0
2d	22.1	33.5
3d	22.2	27.9
4th	20.9	21.4
5th	17.8	19.4
6th	17.1	16.0
7th	21.0	17.8
8th	22.0	13.5
9th	14.7	10.3
10th	13.2	9.9
11th	17.2	13.2
12th	20.5	11.9
13th	18.8	14.5
14th	20.2	10.3
15th	13.3	7.1
16th	14.6	9.2
17th	13.8	9.2
Following 1/2 min.:		
1st	15.9	9.1
2d	19.5	8.9

TABLE 83.—*Respiration-rate and pulmonary ventilation of E. D. B. in periods of transition from grade walking to standing. (Values per minute.)*—Continued.

Date, condition, and period of measurement.	Respiration-rate.	Pulmonary ventilation (unreduced).	Date, condition, and period of measurement.	Respiration-rate.	Pulmonary ventilation (unreduced).
February 25, 1916—cont'd. Standing—cont'd Following 1/2 min.—cont'd.		*liters.*	*February 25, 1916*—cont'd. Standing—cont'd. Following 1/2 min.—cont'd.		*liters.*
3d	18.0	9.4	9th	......	......
4th	17.3	9.9	10th	12.8	8.4
5th	16.8	8.6	11th	12.9	9.1
6th	15.4	9.3	12th	14.4	9.9
7th	16.0	8.0	13th	13.6	9.9
8th	17.3	9.4			

TABLE 84.—*Respiration-rate and pulmonary ventilation of E. D. B. in successive periods of transition from grade-walking to standing (Values per minute.)*

Date, condition, and period of measurement.	Period I.		Period II.		Period III.		Period IV.	
	Respiration-rate.	Pulmonary ventilation (unreduced).	Respiration-rate.	Pulmonary ventilation (unreduced).	Respiration-rate.	Pulmonary ventilation (unreduced).	Respiration-rate.	Pulmonary ventilation (unreduced).
March 10, 1916. Walking, 30 p. ct.; av., 53.3 meters:		*liters.*		*liters.*		*liters.*		*liters.*
Measured in minutes	26.4	56.5	......	......	......	......	......	......
	30.4	73.1	28.7	60.7	30.0	61.7	30.8	60.3
	30.8	68.6	30.3	76.0	29.7	75.5	30.2	72.6
	30.4	71.2	28.0	61.7	32.3	76.6	33.3	66.4
Last full minute	33.3	74.7	30.5	72.4	32.3	76.1	32.4	72.9
Standing, measured in 1/5 min.:								
1st	27.1	52.2	32.1	74.2	28.5	54.8	28.1	52.3
2d	26.8	44.7	30.8	64.0	24.1	39.1	24.6	44.0
3d	31.7	40.2	29.5	51.7	22.4	28.5	23.6	39.8
4th	24.8	27.4	28.7	46.3	23.2	22.5	24.6	33.4
5th	22.0	23.9	28.7	36.9	31.2	27.7	22.7	24.7
6th	21.4	20.3	17.9	16.3	32.0	30.1	25.8	20.9
7th	19.3	18.7	23.3	19.9	24.2	28.0	23.0	19.7
8th	21.2	19.0	18.5	15.7	22.3	21.7	23.5	17.7
9th	18.7	17.1	17.4	13.4	21.1	15.8	23.9	19.0
10th	22.4	19.1	19.2	13.4	23.2	18.8	26.7	18.4
Following 1/2 min.:								
1st	20.2	18.2	21.2	16.4	23.6	18.0	20.9	19.1
2d	18.4	17.0	21.6	17.3	22.8	18.0	22.0	17.4
3d	19.7	18.0	23.6	18.5	21.6	17.8	23.7	18.9
4th	17.7	18.4	20.5	19.2	21.7	18.4	21.7	18.2

TABLE 84.—*Respiration-rate and pulmonary ventilation of E. D. B. in successive periods of transition from grade walking to standing.* (*Values per minute.*)—Continued.

Date, condition, and period of measurement.	Period I.		Period II.		Period III.		Period IV.	
	Respiration-rate.	Pulmonary ventilation (unreduced).	Respiration-rate.	Pulmonary ventilation (unreduced).	Respiration-rate.	Pulmonary ventilation (unreduced).	Respiration-rate.	Pulmonary ventilation (unreduced).
March 10, 1916—cont'd.								
Standing—cont'd.								
Following 1/2 min.—cont'd.		*liters.*		*liters.*		*liters.*		*liters.*
5th	18.2	18.5	19.2	17.9	20.0	18.0	21.1	19.1
6th	16.7	18.2	21.5	18.6	21.6	18.4	18.2	15.0
7th	......	......	19.8	20.1	20.2	17.8	......	......
8th	......	......	17.3	14.3	......	......	......	......
March 11, 1916.								
Walking, 30 p. ct.; av., 52.6 meters:								
Measured in minutes	27.0	52.2	31.0	56.2	31.3	59.0	30.2	56.9
	28.0	63.4	32.0	71.2	31.9	72.2	31.4	67.5
	27.2	53.2	32.5	67.7	32.2	64.5	29.5	57.1
Last full minute	29.7	61.7	31.6	63.8	30.8	68.5	32.0	62.8
Standing, measured in 1/5 min.:								
1st	25.0	47.1	25.7	42.8	24.3	46.3	27.1	50.5
2d	22.7	44.8	27.0	34.3	22.7	34.0	23.4	41.0
3d	26.8	27.8	26.7	27.7	21.8	26.8	23.4	31.1
4th	27.2	24.3	28.8	27.4	19.9	23.3	24.4	28.9
5th	25.2	25.8	22.2	22.2	19.9	18.5	20.3	21.2
6th	22.8	20.9	22.5	19.1	18.5	15.3	20.0	23.0
7th	21.1	17.3	23.2	20.1	24.8	23.0	16.8	13.3
8th	18.2	14.7	22.2	18.9	33.5	22.2	27.3	14.5
9th	18.9	15.7	20.4	17.7	23.1	21.2	19.7	20.2
10th	18.8	15.7	20.3	17.0	19.1	14.3	20.5	16.4
Following ½ min.:								
1st	19.4	14.3	20.3	17.1	21.3	16.6	20.2	13.9
2d	20.8	16.6	20.4	16.8	19.6	16.4	20.2	15.9
3d	18.9	14.8	20.4	17.7	19.0	14.9	21.1	15.3
4th	20.6	15.6	17.3	15.0	19.4	15.3	21.8	16.1
5th	20.1	15.4	20.1	16.6	20.9	16.1	20.9	15.6
6th	18.5	13.8	18.7	16.0	21.3	16.4	22.0	17.0
7th	18.0	14.4	19.7	16.3	21.8	18.0	20.3	14.6
8th	17.2	14.6	......	......	......	......	......	......

CHANGES IN PULMONARY VENTILATION.

The response to the lessened demands of the body indicated by changes in the pulmonary ventilation on the cessation of walking is very noticeable and different in this respect from the results found for the respiration-rate. In the first 12 seconds of standing, the pulmonary ventilation fell in all but three instances and in amounts from 1 to 23 liters. This decrease continued throughout the first and second minutes, and usually longer. By the end of the first minute the fall

TABLE 85.—*Rate of oxygen consumption of E. D. B. in periods of transition from grade walking to standing.*

Date, condition, and period of measurement from transition.	Oxygen consumption (unreduced) per minute.			
	Period I.	Period II.	Period III.	Period IV.
January 1, 1916.				
Standing, measured in 1/5 min.:	*c. c.*	*c. c.*	*c. c.*	*c. c.*
2d	...	...	...	2,150[1]
3d	...	...	...	1,720[1]
4th	...	...	...	1,828[1]
5th	...	...	...	1,505[1]
February 14, 1916.				
Standing, measured in 1/5 min.:				
2d	...	...	...	2,596
3d	...	...	...	2,649
4th	...	...	...	1,429
February 17, 1916.				
Standing, measured in 1/5 min.:				
2d	...	...	...	2,662
3d	...	...	...	1,630
4th	...	...	...	1,278
March 10, 1916.				
Walking, 30 p. ct.; av., 53.3 meters:				
Measured in minutes:				
5th	1,870	...	...	...
4th	1,862	1,861	1,909	1,935
3d	2,279	2,162	2,005	1,670
2d	2,220	2,625	2,243	2,118
1st	2,226	2,182	2,599	2,658
Standing, measured in 1/5 min.:				
1st	2,580	2,311	2,795	2,473
2d	2,473	2,258	2,795	2,096
3d	1,935	2,311	2,150	2,043
4th	1,505	...	1,075	1,881
5th	1,129	1,398	...	1,451
6th	860	1,236	753	1,129
7th	753	...	753	914
8th	484	645	699	645
9th	484	538	538	...
10th	376	484	591	430
Following 1/2 min.:				
1st	366	452	516	452
2d	430	344	430	409
3d	387	344	409	409
4th	366	387	344	452
5th	280	452	387	...
6th	...	409	344	445
7th	...	421	344	...
March 11, 1916.				
Walking, 30 p. ct.; av., 52.6 meters:				
Measured in minutes:				
4th	1,838	1,910	2,023	2,199
3d	1,884	1,984	1,971	1,949
2d	2,022	2,354	2,290	2,172
1st	2,169	2,779	2,324	2,389

[1] Period V.

TABLE 85.—*Rate of oxygen consumption of E. D. B. in periods of transition from grade walking to standing*—Continued.

Date, condition, and period of measurement from transition.	Oxygen consumption (unreduced) per minute.			
	Period I.	Period II.	Period III.	Period IV.
March 11, 1916—cont'd.				
Standing, measured in 1/5 min.:	*c. c.*	*c. c.*	*c. c.*	*c. c.*
1st	2,365	2,311	3,064	2,473
2d	2,365	1,989	2,688	2,903
3d	....	....	1,720	1,881
4th	....	....	1,236	1,236
5th	1,021	914	1,075	968
6th	806	860	968	645
7th	645	645	....	699
8th	538	645	....	591
9th	484	484	484	591
10th	484	430	538	645
Following 1/2 min.:				
1st	387	452	473	538
2d	366	387	452	473
3d	366	387	409	452
4th	323	366	430	387
5th	344	366	387	387
6th	344	366	344	409
7th	301	....	266	445
8th	301	....	....	....

had amounted to 40 to 60 per cent of the ventilation during walking. If the normal ventilation of E. D. B. for the standing position be taken as 11 liters per minute (unreduced), as would appear to be the case from the values in table 81, it is seen that this value was approached in a number of instances in the third minute after walking ceased. These values are not maintained in most of the cases, but are succeeded by a higher ventilation, from which it begins slowly to fall. In most of the records, however, the ventilation appears to be in the region of 15 liters per minute and to be still above the normal standing value after 5 minutes of standing. On but three days (January 1 and 3, and February 25) does the ventilation appear to be adjusted to the pre-walking value before the end of the measurements. This would indicate that the body was striving to eliminate the large excess of carbon dioxide previously formed in the work of walking.

CHANGES IN RATE OF OXYGEN CONSUMPTION (UNREDUCED).

Comparison measurements of the unreduced oxygen consumption during standing and walking experiments were made from the kymograph records on March 10 and 11, 1916, only. These measurements, which, immediately after the transition, were made in one-fifth minutes, are recorded in table 85. A few measurements of the oxygen consumption during standing were also made on January 1, February 14 and 17, 1916. These results are likewise included in table 85, and show that during the first minute of standing after walking ceased there was a contraction in the oxygen consumption ranging from 600 to 1,400 c. c. between the second and the fourth or fifth fractions of the first minute. No measurements were made for the first one-fifth minute of standing on account of irregularities in the record, and no measurements of the oxygen consumption during walking on these dates are available for the transition period. Any real comparison must therefore be confined to the two days for which we have more nearly complete data.

The results for March 10 and 11, 1916, include both walking and standing values for four periods on each day. The first point which attracts attention is the fact that the oxygen consumption during the first two one-fifth minute measurements for standing usually indicates an increase over the walking rate. The tracings in this portion of the transition record were always irregular at their low points, implying that the transition disturbed the normal type of respiration. It is thus difficult to determine the course of the rise in these few seconds, since an error of 2 mm. represents approximately 80 c. c., and a few disturbed respirations at this point could easily introduce an error of double this amount in the probable course. This disturbance presumably represented a temporary alteration in the residual air in the lungs. It is only after these first disturbances have passed that the true change taking place in the oxygen consumption is apparent. This point was reached by the third or fourth one-fifth minute, when the fall amounted to approximately 400 or 500 c. c. By the end of the first minute the oxygen consumption had fallen to approximately one-half of the values found with the subject walking. The drop from this point is almost uniformly progressive during the second minute and continues with somewhat less regularity to the end of the measurement. If, from the data in table 82, the normal unreduced oxygen consumption of E. D. B. for the standing position be taken as 280 c. c. per minute, it is seen that in only two cases is there an approach to this figure by the end of the measurement (see March 10, period 1, and March 11, period 3); that is, during the time that these measurements were extended (5 or 6 minutes), the oxygen consumption continued above the normal standing requirements. It is also seen that, after the first unreliable readings due to a disturbed record, the fall was approximately uniform.

Conclusions Regarding Respiratory Changes in Transition from Grade Walking to Standing and the Reverse.

From these measurements it is thus found that during the period of transition from standing to walking, the respiration-rate responded within 12 seconds and the maximum change was over by the end of the first minute; that the pulmonary ventilation responded within the first 12 seconds to double the standing value, and continued increasing through the third minute, while the oxygen consumption increased

4 to 5 times within the first minute and the increase was practically over within 3 minutes. Under reverse conditions, i. e., in the transition from walking to standing, the respiration-rate fell slowly and irregularly and was not settled nor at its normal value within 8 minutes. The ventilation-rate fell promptly and within 1 minute was one-half of the value found with the subject walking, this decrease continuing, but with diminishing force; after 8 minutes of standing it was still above the normal. The oxygen consumption was in harmony with the pulmonary ventilation, falling continuously but not reaching a pre-walking normal value during the 6 minutes of measurement.

Pulse-Rate in Transition from Standing to Grade Walking.

In the comparison of the pulse-rate for the standing position with that in grade walking (see p. 262), it was seen that the rate in the walking periods increased largely, the size of the increases depending upon the amount of work done. The results are given graphically in figures 30 to 32, inclusive, pages 265 to 267. The duration of the preliminary walking before the experimental period began varied somewhat, but was rarely, if ever, less than 5 minutes, and in most cases more nearly 15 minutes. During this preliminary walking it was assumed that the metabolism and physiological factors had become adjusted to the new demand and that the body functions were acting on a constant, though higher, plane. This assumption was confirmed by the general picture for the respiration, ventilation, and oxygen consumption previously discussed. (See pp. 278 to 287.) The new level in these cases was reached by or before the fourth minute of exercise, and most of the change occurred inside of 1 minute after the exercise began.

To obtain some estimate of the alterations which take place in the pulse-rate during the time of change from quiescence to grade walking, a number of electro-cardiograms were made for E. D. B. in the period extending from one-half minute before the grade walking began through the first or second minute of exercise. In addition, some records were made in the change from walking to standing at the end of the experimental period.

These changing pulse-rates have been termed the transition pulse-rates. To express the rapid alteration in the heart-action under these conditions, we have used the duration of the pulse-cycle. While the most desirable method of recording these changes would naturally be to have the time-intervals on the photographic paper of such size that each pulse-cycle could be readily measured in 0.01 second, the labor and the time involved precluded any extended use of this method. It should be remembered that in all this work our interest was in the pulse-rate and, as explained on page 34, the electro-cardiogram was used simply as a means of determining that factor and not to study the type or peculiarities of the pulse-cycle. On two occasions (February 28 and 29) the paper was run through the camera with such rapidity that it was possible to measure the durations of the individual cycles. Ordinarily, however, the rate of movement was so adjusted that the pulse-rate per minute could be easily counted, but the time-intervals on the paper were too small for the accurate measurement of the duration of the individual pulse-cycle. Therefore, in order to have our period of measurement long enough to secure reasonably accurate readings to 0.01 second, the cycles were measured in groups of 10. The results given accordingly represent the average duration of a pulse-cycle as calculated from the measurement of the time required for a group of 10 pulse-cycles. The changes in the average duration as thus determined give a clearer measure of altering heart-rate than could be obtained by the usual method of counting the pulse.

The changes in the duration of the pulse-cycle in the transition from standing to walking are shown in the four curves in figure 39. In this figure each point on the abscissa represents the average of 10 consecutive pulse-cycles, while the duration of the pulse-cycle is given in 0.01 second as the ordinate. The pulse-rates equivalent to the measured durations are shown on the right. As the duration of the cycle is changing, the time required for a group of cycles also changes, but the approximate elapsed times are indicated for groups of 100 cycles by small figures and inclusion marks below the curves. The point at which the subject began to walk is shown on the curve by the letter *X*.

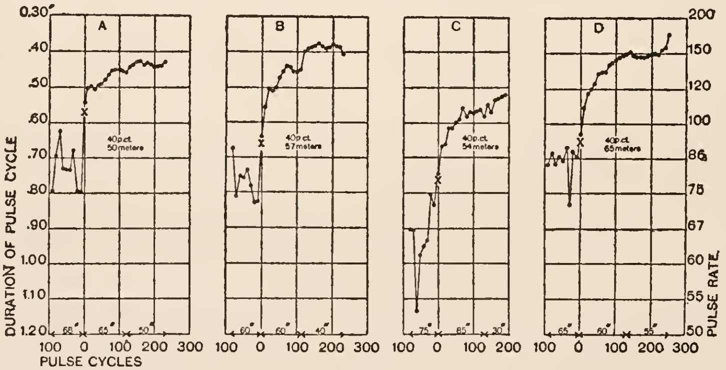

Fig. 39.—Duration of pulse-cycles of E. D. B. in transition from standing to grade walking, as indicated by average cycle duration for measured groups of 10 pulse-cycles.

Beginning of walking at X. A, Feb. 18; B, Feb. 21; C, Feb. 19; D, Feb. 22. The time required for groups of cycles, varying in number, is indicated by small figures and inclusion marks at the bottom of the charts.

The cycles to the left of *X* accordingly represent measurements for the standing position and to the right those for grade walking. The average grades and speeds used in the walking are indicated for each curve.

In figure 39, a noticeable feature is the wide variation in the duration of the pulse-cycles while the subject was standing, as shown by the variability of the portion of each curve at the left of *X*. The measurements for the standing position were made with the same degree of accuracy as those obtained during the walking, and there is no reason to doubt the presence of these wide differences. Measurements of similar character, which were made subsequent to this work and reported by Benedict, Miles, Roth, and Smith,[1] showed like irregularities which were explained by the investigators as due in all probability to a psychical stimulus occasioned by the warning signal for starting. Though no signal for starting was given in the experiments here represented, the explanation may apply to these curves also, for the subject was naturally conscious that walking would begin at any moment, as there were certain routine movements which he would recognize as preceding the start. These irregular factors of duration have one noticeable feature in common, namely, one or more points of a retarded pulse, i. e., of lengthened duration. It does not appear that the lengthening was in any way related to the beginning of walking, though one might expect that it marked the period when the subject realized that the operator was ready to open the air-valve and start the treadmill.

It is also apparent from these curves that the average cycle duration shortened uniformly during walking to a minimum duration which was reached in from 150 to 200 cycles, the greater portion of this change occurring in the first 100 cycles, with the change gradually diminishing. On two days (see curves A and B), a slight tendency to a reaction set in at approximately 100 cycles. The time when the minimum duration was reached is seen to be approximately 1 minute and, except in curve C, this minimum was held with a considerable degree of constancy in the remainder of the record, i. e., to the end of the second minute. It is thus evident that the pulse-rate increased to meet the demand of the added work placed upon the body within approximately 150 cycles and with a time lapse of between 1 and 2 minutes. Beyond this point there would undoubtedly be some rise and some variation, but the greater part of the pulse change occurred in the first minute for the conditions of work illustrated here.

To compare the pulse-cycles over greater intervals of time, a more extended record of five curves is given in figure 40. In these records we have attempted to measure the individual cycles and each point represents the average of 2 cycles thus measured. Since under these conditions there is more or less error in the estimation of fractions of time intervals, not a little of the irregularity shown in the pulse-cycles for standing may be due to this cause. Curve A in figure 40 is a record taken during the middle of a standing period at $9^h\ 44^m$ a. m. on February 28, 1916. Even allowing for the errors of measurement, it is evident that during standing there were constant fluctuations in the duration of the pulse-cycle like those found in the standing portions of the curves in figure 39. Between the minimum and maximum durations there was a total difference of 0.34 second, this change occurring within 8 cycles. The second curve (B), which is not continuous with curve A, includes the transition from standing to walking. Like the curves in figure 39, the standing portion, which is indicated by the reversed numbering of the groups of cycles, shows similar irregularities and marked lengthening in the duration of the cycles previous to the beginning of walking at *X*. The rise in the curve subsequent to the beginning of walking was decided and regular for 20 cycles, or approximately 15 seconds. Thereafter the rise was more gradual, and after 1 minute of walking the rate was fairly uniform at 0.45 second. Curve C is a record taken after the walking had been in progress for 2 minutes and covers a period of approximately 1¼ minutes. During most of this time the pulse-cycle was between 0.5 and 0.4 second in duration, shortening slightly with the time and ending at 0.4 second.

---

[1] Benedict, Miles, Roth, and Smith, Carnegie Inst. Wash. Pub. No. 280, 1919, p. 429.

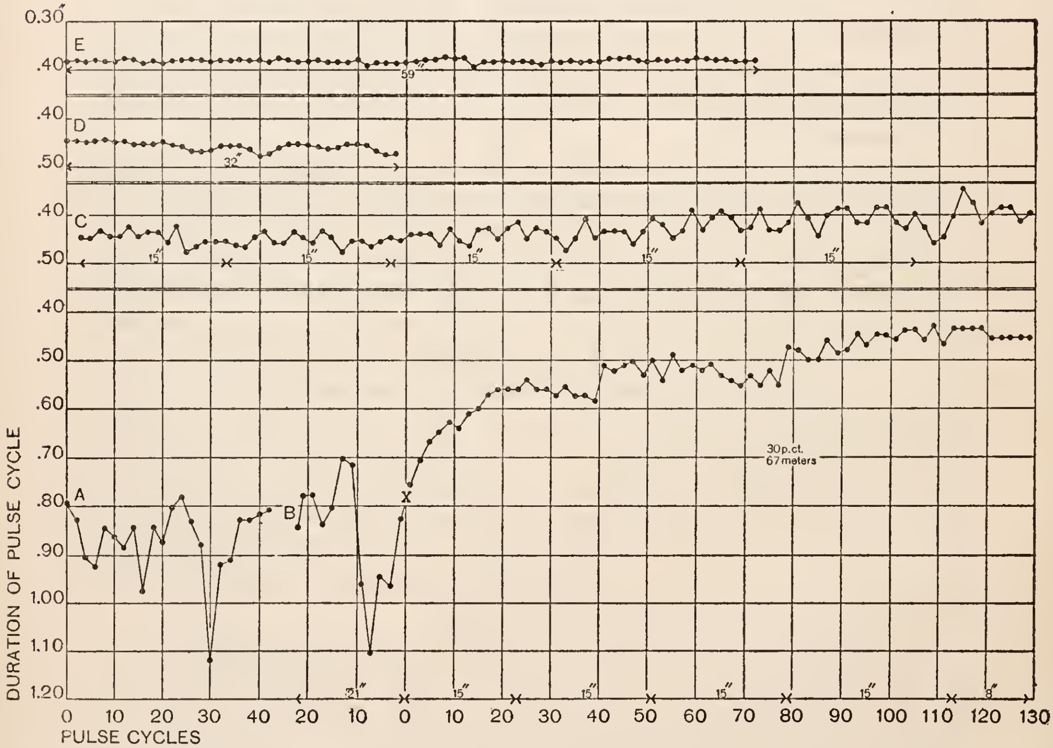

Fig. 40.—Duration of pulse-cycles of E. D. B. in grade-walking experiment of Feb. 28, 1916, as indicated by averages of 2 pulse-cycles, measured individually.

A, standing; B, transition standing to walking; beginning of walking at X; C, D, and E, walking after 2, 26, and 30 minutes, respectively, of continuous walking. Curves D and E with lengthened record of time-interval. The time required for groups of cycles, varying in number, is indicated by small figures and inclusion marks below each curve.

After the subject had been walking continuously 26 minutes, a record was taken in which the photographic paper was put through the camera at a rate of approximately 5 cm. a second, which produced a space interval between the pulse-cycles of from 12 to 15 mm. This permitted measurements with a greater degree of accuracy, the results being given in curves D and E. As in the other curves, the points represent the averages of 2 cycles. The durations of the pulse-cycles shown in curve D are practically constant, varying from 0.44 to 0.48 second throughout a record of three-quarters of a minute, thus indicating a more uniform duration of the pulse-cycle than that shown by curve C. The second record taken by this method (curve E) was made after a total period of walking of 30 minutes. During the 144 cycles in this curve, the length of cycle varied only from 0.37 to 0.39 second. These two records show a remarkably constant cycle duration after a sufficient period of time had elapsed for the body to become adjusted to the needs of the exercise of walking. While they

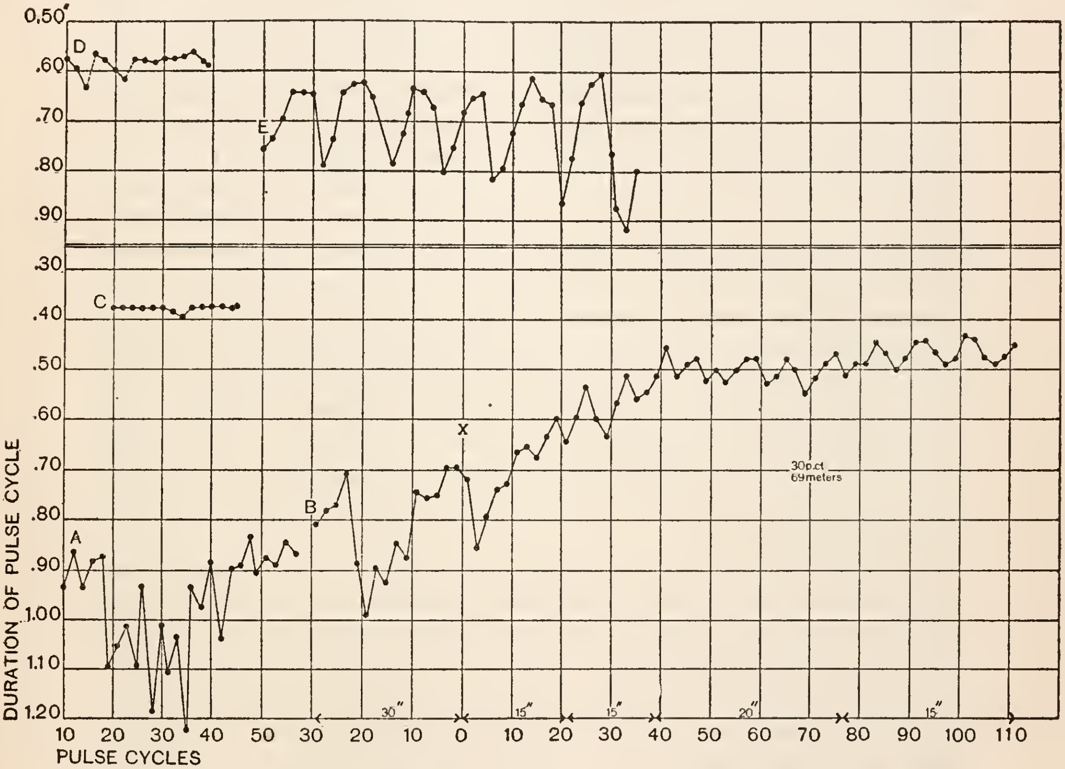

FIG. 41.—Duration of pulse-cycles of E. D. B. in grade-walking experiment of February 29, 1916, as indicated by averages of two pulse-cycles measured individually.

A, standing; B, transition standing to walking, beginning of walking at X. C, walking 26 minutes after X. D and E, standing 8 and 14 minutes, respectively, after end of walking. All curves except B with lengthened record of time-interval. The time required for groups of cycles, varying in number, is indicated for curve B by small figures and inclusion marks at the bottom of the chart.

also indicate that the irregularities in the duration of the pulse-cycle in the few seconds preceding walking may in part be due to errors of measurement, it is believed, for reasons given later, that these irregularities are present, and that the relative behavior of the pulse for standing and walking as shown by the curves in figure 40 is correct.

Figure 41 gives 5 curves of the duration of the pulse-cycles on February 29, each point, as in figure 40, being the average of 2 cycles. Curve A represents pulse-cycles with the subject standing in the second period of the day, and exhibits like variations to those referred to in the discussion of other curves. In the corresponding curve A of figure 40, although the individual pulse-cycles were measured, the time-intervals on the photographic paper were small, and it was suggested that some of the irregularities in the curve may have been due to errors of measurement. In curve A of figure 41, however, the time-interval was lengthened and this source of error was thus largely removed, but the same variation in the pulse-cycles for standing is apparent. The maximum variations during this record are as large as 0.4 second, with 0.3 second as the greatest difference between two successive points. In curve B, the time-interval was not lengthened and the errors in estimating the fractions of a second are therefore greater. The standing portion of the curve, as in the curves earlier discussed, shows gross variations in the cycle duration. On the transition to walking there is a lengthening of pulse-cycle duration which is directly at variance with the other records given in figures 39 and 40. The question may fairly be raised if the time of transition were correctly indicated on the photographic paper and if it may not have been a second or two later. As in the preceding figures, the major portion of the rise in the curve had taken place by the measurement of the fortieth or fiftieth cycle, with an average cycle duration at that time of 0.5 second. Thereafter, the change in the duration was but slight, reaching an approximate value of 0.45 second at the end of the curve, which covers a time-interval of 65 seconds.

After the subject had been walking 26 minutes, a short record was made (curve C) in which the time-intervals on the record were lengthened by increasing the speed of feeding the paper to the camera. It may be noted that in this curve (C), the duration of the pulse-cycle had further shortened to 0.36 to 0.39 second, and there is less variation between the readings. This is in harmony with curves D and E of figure 40, which illustrated the regularity of the pulse-cycle duration after a continued period of exercise. Curves D and E in figure 41 will be considered subsequently, as they represent records taken when the man was standing after walking.

From these measurements of the durations of the pulse-cycle in the transition from standing to grade walking, there is evidence that the standing pulse varied widely between successive cycles; that the interval preceding walking is likely to be influenced by psychical effects due to the anticipation of the starting of the treadmill; that most of the rapid shortening of the cycle duration after the beginning of walking occurs within 25 or 30 cycles, or about 15 to 20 seconds, and is over within 1 minute; and that the shortening of the duration thereafter is very gradual and may continue for a period of 25 to 30 minutes.

Pulse-Rate in Transition from Grade Walking to Standing.

The changes in the duration of the pulse-cycle occurring when the subject stopped walking and stood are shown in curves D and E in figure 41 and also in four curves in figure 42. Curve D in figure 41 represents the records obtained after the subject had stood 8 minutes. Like curve C in the same figure, this record was made with the time-intervals lengthened by an increase in the speed of the paper through the camera, and is thus largely free from errors of measurement. During this record there was difficulty with the feed of the paper at the points indicated by the broken lines, and the record is not continuous for 5 to 7 seconds on account of the slipping of the feed-rolls and overexposure of the paper. Notwithstanding this, the record shows that the duration of the cycle had lengthened from the walking duration of 0.4 second to approximately 0.6 second, and, further, that the variations of a standing pulse had begun to appear, which have already been noted in previous discussion of figure 40 and of curve A in this figure.

Curve E is similar to but not continuous with curve D, and represents the pulse measured with lengthened time-intervals after the subject had been standing for 14 minutes. A wide variation in the duration of cycles is seen in the curve, but this variation differs from that in the other standing records, as here a pronounced rhythm is present, occurring with each 12 to 14 cycles. At first thought it might be said that this rhythm was connected with the respiration, but assuming the average pulse-cycle duration in the curve is 0.73 second, the time-intervals for the rhythm would be nearly 10 seconds, corresponding to a respiration-rate of 6 respirations per minute. As seen in table 86 (p. 306), the average respiration-rate 24 minutes after walking ceased on February 29 was 16.9, and it is unlikely that it could have approached the rate required by the estimated length of the rhythm. The record was made during the middle of the period, when conditions were free from any disturbances which might have a tendency to stimulate or retard the pulse-cycle. The cause of the evident rhythm remains unexplained.

The changes in the duration of the pulse-cycle after walking ceased are also shown in the four curves in figure 42. These curves are constructed in the same way as those in figure 39, each point indicating the average duration of a pulse-cycle as calculated from the measurement of a group of 10 cycles, and each square in the figure representing 100 cycles. The ordinates, however, have been drawn to a larger scale than in figure 39. The variations in the pulse-cycles thus appear larger than in the curves in figure 39.

In curve A the duration of the pulse-cycle for the subject walking is between 0.33 and 0.34 second. During the first 50 cycles following the transition, the duration lengthened to 0.36 second, with a total lengthening of but 0.02 to 0.03 second. In the next 50 cycles there was a further fall in the curve to 0.42 second, and by the end of 150 cycles the duration was between 0.45 and 0.46 second, or a lengthening of the cycle of but little more than 0.1 second. This is in decided contrast to the rapid rate of change shown in the transition from standing to walking, when most of the change occurred within 100 cycles. The 150 cycles of curve A occupied approximately 1 minute, and the following minute brought the duration to but 0.49 second. The return of the cycle duration during the first few minutes of standing is therefore slow in comparison to the transition in the change from standing to walking.

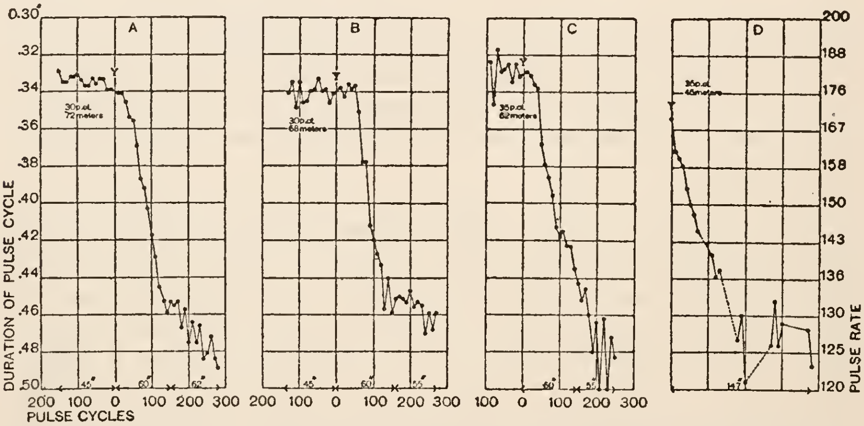

FIG. 42.—Duration of pulse-cycles of E. D. B. in transition from grade walking to standing, as indicated by average cycle duration for measured groups of 10 pulse-cycles.

Beginning of standing at Y. A, Feb. 12; B, Feb. 14; C, Feb. 17; D, Feb. 15. The time required for groups of cycles, varying in number, is indicated by small figures and inclusion marks at the bottom of each chart.

The behavior of the pulse-cycle in curve B is almost the same as that found in curve A. The duration just previous to the transition is practically the same. At the end of 100 cycles the duration has lengthened to 0.42 second, or but 0.08 second. At 150 cycles, occupying approximately 60 seconds, the duration was about 0.46 second. Two minutes of standing resulted in a total lowering of the duration of the pulse-cycle 0.12 second. This curve shows some lag at the transition which other curves do not show.

In curve C the duration of the pulse-cycle lengthened from 0.33 second preceding the transition to standing to 0.37 second in 50 cycles, while in 150 cycles after the walking ended, occupying approximately 60 seconds, the duration lengthened to 0.44 second, or a total lengthening of 0.11 second. This rate of lengthening agrees with that found in the two preceding curves, namely, in 150 cycles of approximately 60 seconds of elapsed time, the change in the average duration of the cycle was but little over 0.1 second, and by the end of 2 minutes the lengthening of the duration of the cycle did not reach 0.2 second. The duration of the pulse-cycle at the end of 2 minutes is thus less than 0.5 second, or, in terms of pulse-rate per minute, the change has been from 176 to 125 beats.

Curve D is composed of 5 records, covering a duration of 147 seconds, and therefore is not continuous. Consequently, it must be considered on a time basis rather than according to the number of consecutive pulse-cycles. For the first 70 cycles the record was continuous and the elapsed time was 30 seconds. In this time the duration lengthened to about 0.41 second, or a total lengthening of 0.06 second. At the end of 1 minute the duration fell another 0.01 second, and at the end of the record, after 2 minutes and 27 seconds of standing, the duration of the pulse-cycle was 0.49 second, or 0.14 second longer than at the transition. At the end of 1 minute or thereabouts, all four of these curves begin to exhibit a marked irregularity in the duration of the pulse-cycles, similar to that seen for the pulse during standing in figures 39, 40, and 41, with some suggestion of a rhythm in curves A and C, recalling that seen in curve E in figure 41.

From these curves it appears that the response to the change from walking to standing is rapid, although slightly slower than with the change from standing to walking; also, that the lengthening of the pulse-cycle after walking had ceased continues at a uniform rate for approximately a minute, during which time the rate decreases from 40 to 50 beats a minute. After the immediate drop in the first minute, the change apparently becomes less marked, with wide fluctuations in the cycle durations.

After-Effects of Grade Walking.

As a part of the routine of the research, a few standing experiments were made with E. D. B. following periods of grade walking, for a study of the after-effects of the exercise on the standing metabolism. The results are compared in table 86, in which the average pre-walking values for the day are taken from table 6 and the grade-walking values are drawn from table 16. In each case the length of the period of walking, with the grade and the speed, also the length of period of rest (sitting) between the walking and standing observations, are given in table 86. As the values for December 21, 1915, to February 17, 1916, inclusive, were obtained immediately after walking ceased, they naturally represent rapidly changing values, especially in the earli part of the period.

The experiments of February 26 to 29, inclusive, have three post-walking periods each, with an interval of rest, i. e., sitting, of approximately 20 to 24 minutes before the measurements in the first standing period began. The last period on each of these days was approximately 2 hours after walking. The changes in these last periods would

TABLE 86.—*Metabolism of E. D. B. when standing after grade walking in experiments without food.* (*Values per minute.*)

Date and experimental conditions.[1]	Average respiration-rate.	Average pulmonary ventilation (reduced).	Average pulse-rate.	Average body-temperature.	Carbon dioxide.	Oxygen.	Respiratory quotient.	Heat (computed).
Dec. 21, 1915:		*liters.*		*°C.*	*c. c.*	*c. c.*		*cals.*
Standing before walking	14.8	8.9	58	....	190	207	0.92	1.02
Walking 1^{h}40^m; 20 p. ct., 70 m. p. m.	26.0	37.0	....	....	1,596	1,784	.90	8.78
Standing, no rest	18.3	....	105	....	322	380	.85	1.85
Dec. 22, 1915:								
Standing before walking	12.8	8.0	....	....	190	218	.87	1.07
Walking 1^{h}34^m; 20 p. ct., 70 m. p. m.	25.7	34.2	....	....	1,554	1,748	.89	8.59
Standing, no rest	19.5	13.6	102	....	307	367	.84	1.78
Dec. 31, 1915:								
Standing before walking	15.2	9.7	75	....	211	257	.82	1.24
Walking 1^{h}2^m; 20 p. ct., 80 m. p. m.	27.6	43.9	....	....	2,042	2,270	.90	1.18
Standing, no rest	22.2	16.2	128	....	405	490	.83	2.37
Jan. 3, 1916:								
Standing before walking	15.6	9.5	....	....	210	250	.84	1.21
Walking 1^{h}39^m; 25 p. ct., 43 m. p. m.	23.8	29.1	....	....	1,183	1,451	.82	7.00
Standing, no rest	19.2	12.5	....	....	284	352	.81	1.69
Feb. 12, 1916:								
Standing before walking	14.4	8.8	65	36.80	191	244	.78	1.17
Walking 1^h; 30 p. ct., 72 m. p. m.	28.4	59.6	163	37.75	2,471	2,613	.95	13.03
Standing, no rest	21.6	18.4	122	....	455	528	.86	2.57
Feb. 14, 1916:								
Standing before walking	14.9	9.2	77	37.10	196	240	.82	1.16
Walking 1^h; 30 p. ct., 68 m. p. m.	27.8	54 5	166	37.98	2,311	2,481	.93	12.31
Standing, no rest	22.1	17.8	123	38.50	417	511	.82	2.47
Feb. 15, 1916:								
Standing before walking	16.2	10.1	79	36.94	207	261	.79	1.25
Walking 1^{h}21^m; 35 p. ct., 45 m. p. m.	27.7	40.5	145	38.29	1,732	2,007	.86	9.78
Standing, no rest	21.1	14.9	125	38.53	369	452	.82	2.18
Feb. 16, 1916:								
Standing before walking	15.5	9.4	....	36.88	205	255	.80	1.22
Walking 19^m; 35 p. ct., 58 m. p. m.	29.6	54.5	174	38.27	2,267	2,495	.91	12.32
Standing, no rest	20.9	15.8	131	....	382	476	.80	2.29
Feb. 17, 1916:								
Standing before walking	16.5	10.0	85	37.13	210	267	.79	1.28
Walking 57^m; 35 p. ct., 62 m. p. m.	29.1	61.8	177	38.08	2,507	2,725	.92	13.48
Standing, no rest	21.3	16.7	122	38.51	424	520	.82	2.51
Feb. 26, 1916:								
Standing before walking	16.1	9.4	70	37.01	212	251	.84	1.22
Walking 1^{h}4^m; 30 p. ct., 69 m. p. m.	30.2	54.6	153	37.61	2,387	2,592	.92	12.83
Standing after 24^m rest	16.7	9.7	96	38.13	210	273	.77	1.30
Standing, 1^{h}18^m after walking[2]	16.7	9.5	81	37.22	206	245	.84	1.19
Standing, 2^{h}8^m after walking[2]	16.1	9.1	73	36.71	210	267	.79	1.28
Feb. 28, 1916:								
Standing before walking	15.1	9.1	69	36.74	213	244	.87	1.19
Walking 1^{h}2^m; 30 p. ct., 67 m. p. m.	30.2	55.0	150	37.11	2,374	2,508	.95	12.50
Standing after 20^m rest	15.4	10.0	101	38.09	239	282	.85	1.37
Standing, 1^{h}15^m after walking[2]	15.6	9.6	83	37.30	223	252	.88	1.23
Standing, 1^{h}55^m after walking[2]	16.6	9.9	80	37.19	218	266	.82	1.28
Feb. 29, 1916:								
Standing before walking	14.8	8.8	68	36.70	183	230	.80	1.10
Walking 34^m; 30 p. ct., 69 m. p. m.	32.1	56.5	153	37.44	2,284	2,491	.92	12.33
Standing after 24^m rest	16.9	10.3	....	38.04	213	291	.73	1.37
Standing, 1^{h}1^m after walking[2]	15.9	9.4	88	37.18	198	276	.72	1.30
Standing, 1^{h}50^m after walking[2]	16.3	9.5	82	36.83	191	245	.78	1.17

---

[1] The values for standing before walking and for grade walking are average values for the day. See tables 6 and 16, pp. 46 and 78. Those for standing after walking are period values.

[2] During this interval between the walking and standing, the subject sat for a part of the time.

naturally be less, and it might be expected that values of approximately the pre-walking rate would be found. In experimental periods continuing as long as those employed by us in this study it was naturally not expected that the measurements would show the gradations that could be obtained by other methods; nevertheless a general comparison may be made of the metabolism preceding and following walking.

In the experiments of December 21 to February 17, inclusive, it is seen that the data for the respiration, ventilation, and pulse show no close approach to the pre-walking values since they were obtained immediately on the cessation of walking. It may be noted, however, that although the percentages vary, the ventilation-rate remained at a higher level, relatively, than the respiration-rate, the former averaging approximately 70 per cent above the pre-walking average and the respiration-rate approximately 40 per cent.

In the first of the post-walking periods of February 26 to 29, following 20 or more minutes of rest, both respiration and ventilation, though much reduced, were still above the pre-walking values. In the third standing period, which was approximately 2 hours after walking had ceased, the data for February 26 show that the respiration-rate and pulmonary ventilation had fallen to the pre-walking rate during the interval, but that on February 28 and 29 these factors were still above the pre-walking averages. The pulse remained above the pre-walking rate on all of these days. This is in keeping with the results reported by Benedict and Cathcart,[1] who found that the pulse-rates did not readily return to the pre-walking level after such prolonged exercise.

Only a few measurements of the body-temperature are available for comparison, but these are included in table 86. The post-walking temperatures appear here to be higher than those obtained in the walking periods. This is contrary to the curves in figures 33 to 37. inclusive, which show a rapid fall in body-temperature after walking ceased. This difference in direction is due to the fact that the temperature values for walking given in table 86 represent averages of all the walking periods of the day, and thus no sharp comparison of the walking and standing values is possible here. The special interest in this connection is, however, the comparison between the temperatures with the subject standing before and after walking. It is seen that for the periods of standing immediately after walking, the average body-temperature is 1.5° C. higher than the pre-walking temperature and for the first post-walking periods on the days when a rest interval of but 24 minutes intervened the difference is but little less. By the second post-walking period, the temperatures are still nearly 0.5° C. above the pre-walking temperature. It is not until the third period, representing a time-interval of 2 hours after walking ceased, that the temperature may be said to approximate anything like the original values.

---

[1] Benedict and Cathcart, Carnegie Inst. Wash. Pub. No. 187, 1913, p. 153.

The after-effects of exercise on the gaseous exchange have recently been studied by Campbell, Douglas, and Hobson,[1] and by Krogh and Lindhard,[2] who followed the changes through brief intervals. These authors find, in harmony with Zuntz, with Benedict and Cathcart, and with others, that the respiratory quotient increases when the work stops; after a brief period it falls to a value somewhat below normal.

The values here reported for 15-minute periods do not, of course, show the stimulated respiratory quotient for the post-walking periods which, according to Krogh and Lindhard, occurs approximately 1½ minutes after the end of walking. In the standing periods following immediately after the cessation of walking (December 21 to February 17), the respiratory quotient is lower than during the walking period, and but little different from the pre-walking quotients. This is probably explained by the fact that the quotients for a period following immediately the cessation of walking would be influenced by the high values referred to above as occurring for a short time. It is only when the periods are taken after the temporary high respiratory quotients have passed that the after-effects of walking become evident. All of the post-walking periods of February 26 to 29 on which there was an interval of rest following the walking indicate a lowered respiratory quotient in relation to both the pre-walking and the walking respiratory quotients. On two of these days the subject had walked somewhat over an hour and on the last day about half that time.

Campbell, Douglas, and Hobson conclude that the possible presence of lactic acid in the muscles is alone not sufficient to explain the behavior of the respiratory quotient following the cessation of work and are inclined to believe with Zuntz and with Benedict and Cathcart that the probable explanation is that during the period of walking the glycogen reserve in the body is depleted and that during the subsequent periods proportionally less carbohydrate than fat is consumed in the body metabolism.

A rough estimate of the amounts of glycogen consumed during 1 hour of walking on the basis of an oxygen consumption of 2,500 c. c. per minute and a respiratory quotient of 0.90 is as follows: The total energy produced in 1 hour would be approximately 750 calories; if 60 per cent of this energy were derived from carbohydrate to produce the respiratory quotient of 0.90, as assumed by Magnus-Levy,[3] and 4.23 calories be assumed as the heat-production from 1 gram of glycogen, the total amount of glycogen consumed in 1 hour of walking would be somewhat over 100 grams, i. e., more than one-fourth of the amount believed to be present normally in the body. Benedict and Cathcart[1] report low respiratory quotients 5 hours after exercise, and Zuntz and Schumburg[2] maintain that the carbohydrate reserve was not established with their subject until the following day.

---

[1] Campbell, Douglas, and Hobson, Phil. Trans., London, 1920, Ser. B, **210**, p. 1.

[2] Krogh and Lindhard, Journ. Physiol., 1920, **53**, p. 431.

[3] Magnus-Levy, in von Noorden's Handbuch der Pathologie des Stoffwechsels, Berlin, 2d ed., 1906, **1**, p. 207.

The stimulating effect of walking is also seen from the experiments of February 26 to 29, in that the gaseous metabolism remained above the pre-walking values even after a lapse of 2 hours following the cessation of walking. Only on February 26 did the metabolism reach the pre-walking values in the case of the carbon dioxide, for on both of the other days the carbon dioxide was still slightly above standing normal requirements at the end of the observations. The oxygen consumption, which is the best index of the metabolism, was above the pre-walking requirements by approximately 7 per cent after the lapse of 2 hours.

SUMMARY OF RESULTS.

In the preceding pages it has been found that the average standing metabolism obtained with the subjects studied was 1.18 calories per kilogram of body-weight per hour, or 28.4 calories per 24 hours. (See table 19.) This, when compared with average metabolism for the lying position of 25.3 calories per kilogram of body-weight per 24 hours (see table 17), represents an increase for the standing position of 12 per cent.

When the standing requirements are used as a basis, it is found that the increase in the energy expended in horizontal walking over the energy output for the standing position varied for the 8 subjects from 0.454 to 0.618 gram-calorie for each horizontal kilogrammeter, i. e., the transportation of 1 kilogram a distance of 1 meter in a horizontal direction. For the two subjects W. K. and E. D. B., with whom most of the work in this research was done, the increase for the horizontal walking in the energy expended was 0.490 and 0.478 gram-calorie, respectively, for each horizontal kilogrammeter. These values are below the average value used by other investigators, but show good agreement. The total energy expended per meter increase in speed was not measurably affected until a speed of 80 meters a minute was reached, beyond which point each meter increase in speed required a proportionately greater increase in the energy consumption. (See table 37.)

In grade walking the total heat expended increased uniformly per kilogrammeter of work performed at each grade, but was somewhat less when the same amount of work was derived from a high grade and a low speed than when due to a low grade and high speed. (See figs. 21 and 22.) The total outlay was from 15 to 12 gram-calories per kilogrammeter for amounts of work ranging from 300 to 600 kg. m. per minute, and from 12 to 10 gram-calories per kilogrammeter when the work was between 1,000 and 1,500 kg. m. per minute. (See also table 62.)

---

[1] Benedict and Cathcart, Carnegie Inst. Wash. Pub. No. 187, 1913, p. 172.

[2] Zuntz and Schumburg, Physiologie des Marsches, Berlin, 1901, p. 255.

The average increment in the heat-output due to grade walking was approximately 7.5 gram-calories per kilogrammeter of work performed. From the results of this study it may be said that the net efficiency with which a person can walk up-grade is not far from 30 per cent when the work is under 500 kg. m. per minute, but when the work amounts to more than 500 kg. m. per minute, the efficiency decreases as the work increases. (See table 69.)

The measurements of the pulmonary ventilation during grade walking show that the increase in this physiological factor for each increase of 100 kg. m. of work was from 3 to 5 liters, while the total percentage increase with excessive work was as much as 850 per cent above the standing requirement. (See tables 76 and 77.) This enormous increase indicates the wide margin which must be provided in designing gas-masks to be worn during excessive muscular work.

During grade walking, the respiration-rate for the subject E. D. B. showed constant increase over the standing value of 1.2 respirations for each 100 kg. m. increase in the work when over 500 kg. m. of work was done. With the subject W. K. the increase over the standing respiration-rate was more nearly 2 respirations per 100 kg. m. (See tables 74 and 75.) The percentage increase over the standing rate was from 8 to 10 per cent for W. K., while for E. D. B. the increase was as high as 40 per cent for the first 100 kg. m., but fell rapidly with increase in the amount of work and became constant at approximately 8 per cent.

In horizontal walking the pulse-rate frequently was less than that with the subject standing, even with an increase in the metabolism of 100 to 200 per cent. During grade walking, the pulse-rate showed a practically uniform increase with the increase in the amount of work performed. The increment in the pulse-rate over the rate found for the standing position rose rapidly with the increase in the work performed; though the percentage increase per 100 kg. m. of work remained fairly constant, considerable differences were shown between individuals. (See tables 78 and 79.)

The body-temperature showed increases as high as 2° C., indicating for a body-weight of 60 kilograms a storage of heat in the body of approximately 100 calories.

From the measurements taken at the time of transition from standing to grade walking, it is believed that in most cases the body adjusts itself to the new demands as to pulse, respiration-rate, pulmonary ventilation, and oxygen-supply by the end of the third minute, and by far the larger part of the adjustment has occurred within 30 seconds. The recovery after exercise, however, is not so prompt, and the after-effects of the walking persist for a much longer time before initial conditions are reestablished.

GASEOUS EXCHANGE AND PHYSIOLOGICAL REQUIREMENTS FOR LEVEL AND GRADE WALKING

By Henry Monmouth Smith

Published by the Carnegie Institution of Washington
Washington, April, 1922

MBL/WHOI LIBRARY
WH 18LX Q